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DEPARTMENT OF THE INTERIOR

FRANKLIN K. LANE, SECRETARY

BUREAU OF MINES

VAN. H. MANNING, DIRECTOR

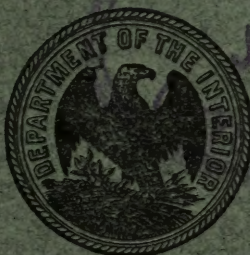
INSTRUMENTS FOR RECORDING CARBON
DIOXIDE IN FLUE GASES

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BY

J. F. BARKLEY AND S. B. FLAGG

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ENGIN STORAGE



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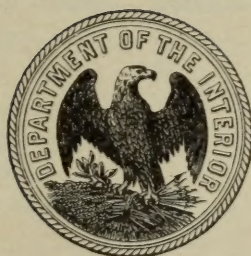
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INSTRUMENTS FOR RECORDING CARBON DIOXIDE IN FLUE GASES.

By J. F. BARKLEY and S. B. FLAGG.

INTRODUCTION.

In the past few years an awakened activity in power-plant economies has resulted in a marked improvement in the equipment for generating and utilizing steam. Although the improvement in design and construction of steam-driven prime movers has been greater than that of the steam-generating equipment, the economies obtained with the more efficient engines and turbines have stimulated interest and activity in eliminating unnecessary boiler and furnace losses.

Much attention has been given to the boiler room in efforts to obtain proper combustion of the coal, because of the importance of the coal item in costs of power production. As evidence of this increasing interest may be cited the record of the development within the past few years of new apparatus for the analysis of flue gases. Many new forms of apparatus have appeared, including those for the determination of carbon dioxide, oxygen, and carbon monoxide, and others for indicating and for recording the content of carbon dioxide only, as carbon dioxide content is usually a good indicator for the control of furnace operation.

Because of the large number of steam-power plants operated by the Federal Government and the number of CO₂ recorders used therein the Bureau of Mines undertook to collect information regarding the practical application of such recorders. Articles published from time to time concerning CO₂ recorders have been mostly descriptive, giving little reliable information as to the results that could be expected from the various types of instruments in ordinary practice, and most of the tests made have been of a laboratory nature.

Tests of several different types of recorders were made under service and laboratory conditions in order to obtain needed information. The purpose of the Bureau of Mines in publishing the results is to show the factors which may affect the accuracy of a CO₂ recorder and the manner in which a recorder should be tested. Readers should note that the remarks on different recorders apply to the instruments tested and not to later instruments of the same makers.

In the course of the tests the following details were determined:

1. The lag in recording changes of composition of a flowing gas.
2. The accuracy of each type of recorder.

3. The variable factors affecting the operation and accuracy of each type.

4. The repairs and renewals necessary.

5. The kind and amount of attention required.

To acquire data relative to the first three items special tests of a laboratory nature were conducted, whereas the information relative to items 4 and 5 was obtained by operating the instruments for a period of several months under conditions practically the same as would be met in a commercial steam-power plant having only a day load. In connection with this work some experiments were made to ascertain the effect of minor changes in the installation and the operation of the instruments. The instruments were numbered consecutively, the number assigned to each instrument being noted below. Throughout this report the instruments are, for convenience, designated by number. The CO₂ recording instruments tested were as follows:

1. The bimeter CO₂ recorder, made by the Cambridge Scientific Instrument Co., Cambridge, England.

2. The Simmance-Abady CO₂ recorder, made by the Precision Instrument Co., Detroit, Mich.

3. The "Sarco" automatic combustion (CO₂) recorder, Sarco Engineering Co., New York, American representative.

4. The "Telezometer" CO₂ recorder, made by G. A. Schultze, Berlin-Charlottenburg, Germany.

5. The Uehling CO₂ machine, made by the Uehling Instrument Co., Passaic, N. J.

The indicating instruments tested were as follows:

6. The CO₂ thermoscope, made by the Underfeed Stoker Co., London, E. C.

7. Dr. A. Schmid's pocket CO₂ indicator, made by J. G. Cramer, Zurich, Switzerland.

The makers of the instruments mentioned each consented to having the Bureau of Mines make the tests outlined, with the understanding that the results would be published.

ACKNOWLEDGMENTS.

The authors wish to express their appreciation of the interest shown by the Precision Instrument Co., the Sarco Engineering Co., and the Uehling Instrument Co., and by Herman Bacharach, of Pittsburgh, Pa., representative of J. G. Cramer and G. A. Schultze, who loaned their instruments for the tests and assisted in every way possible. The authors are also indebted to F. K. Ovitz, assistant chemist, and L. L. Satler, jr., junior chemist, of the Bureau of Mines, for their cooperation.

DESCRIPTIONS OF INSTRUMENTS AND INSTRUCTIONS FOR THEIR INSTALLATION AND OPERATION.

BIMETER CO₂ RECORDER. INSTRUMENT 1.

DESCRIPTION.

Figure 1 shows the internal parts and connections of the bimeter CO₂ recorder. The apparatus consists of two gas meters m_1 and m_2 , an absorption box e , a water-jet suction pump b , and a recording mechanism f , g . The water-jet suction pump or aspirator b , with a consumption of about $2\frac{1}{4}$ gallons per hour, draws about $1\frac{1}{2}$ cubic feet of the flue gas through the instrument per hour. The gas entering at d is cooled in the first chamber of the cooler k , and then measured in meter m_1 . The CO₂ is then extracted from the gas in the absorption chamber e containing lime. As, during this chemical process, the remainder of the gas becomes heated, it is again cooled to its former temperature by being passed through a second chamber of the cooler k . From the cooler the gas is led to the second meter m_2 to be again measured, and is thence allowed to escape to the atmosphere by way of the aspirator b and the water vessel c .

The water used in the operation of the instrument enters at the cock a and flows through the cooler k into the aspirator b . It there draws in the flue gas, and the mixture of water and gas passes into the water vessel c . From this the water escapes through an overflow drain pipe h and the gas bubbles into the atmosphere.

The two gas meters are filled with oil, and are so arranged that when no absorption takes place the meter m_2 runs about 4 per cent slower than the meter m_1 . Thus, when no CO₂ is absorbed, the recording pen is made to record lines about 3 or 4 mm. in height. The actual height of these zero marks is immaterial so long as they terminate at the zero line of the chart.

This recording pen is actuated by means of a differential drive f , operated by the two meters. On an average 20 to 25 analyses may be recorded per hour, the number being dependent on the volume of the flue gases passing through the instrument. The number may be regulated by adjustment of a throttle p , placed in the gas passage

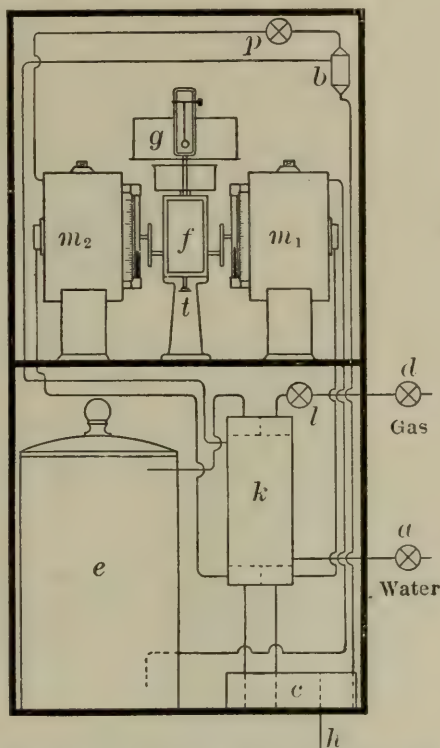


FIGURE 1.—Internal parts and connections of bimeter CO₂ recorder.

near the aspirator *b*. If throttle *p* becomes clogged it can frequently be cleaned by closing it entirely, then reopening.

Figure 15 shows instrument 1 installed for tests.

INSTRUCTIONS FOR SETTING UP INSTRUMENT.

The filter for instrument 1 is placed as close as possible to the sampling tube at the beginning of the gas line. The upper part of the soot filter is filled with wood shavings and excelsior, as shown in figure 2, or excelsior can be used entirely. The filter contents should not be packed tightly. The filled upper part is placed in the lower part, which is filled with water so as to form a water seal. In order

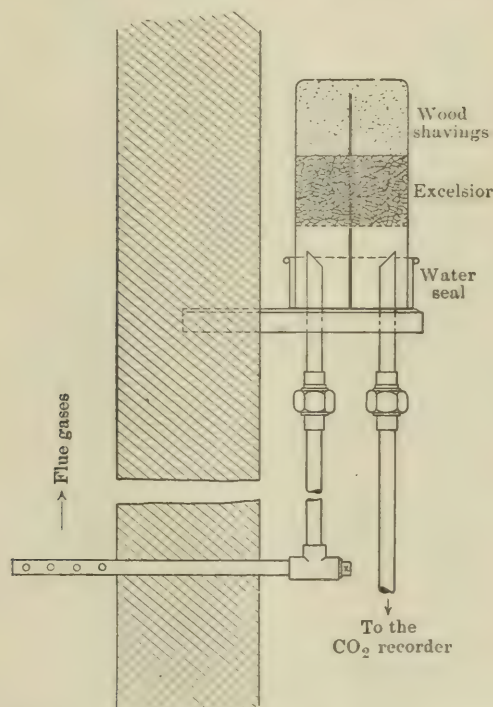


FIGURE 2.—Soot filter and connections, bimeter CO_2 recorder.

that the water may not evaporate a little oil is poured on its surface.

The recorder should be suspended vertically on hooks or screws fixed at a height of about $4\frac{1}{2}$ feet above the floor. The water tank supplied is then fixed vertically above the recorder by means of screws set into the wall at a height of about 21 inches above the recorder supports. The iron tube supplied should next be screwed to connect the water tank to the water cock fixed to the recorder connection *a* (fig. 1).

The water necessary for operating the apparatus may be taken from the ordinary house supply or from a reservoir by means of a half-inch pipe. A float valve in the water tank controls the supply of the

water, but the insertion of a stopcock immediately in front of the tank is recommended. If the water contains impurities filtration may be necessary. It is well to attach to the water line a vertical drain pipe with cock in such a manner as to permit draining of the instrument each time before it is started. Such drainage tends to prevent the accumulation of dirt in pockets. The gas connection at *d* (fig. 1) is made by a half-inch gas pipe from the main gas line to the recorder.

The gas meters m_1 and m_2 are now filled with the oil supplied. Cock *l* is opened to the atmosphere, and the plugs at the top of both meters are also opened, the gas and water cocks *d* and *a* being closed. The oil is poured into the meters by means of a bent funnel supplied for this purpose, and the position of the oil is correctly set on the zeros of the scales. The meter drums are once slowly rotated by

hand in order to get rid of the air bubbles in the corners; and if necessary the position of the oil is corrected. The plugs on the meters are then replaced tightly. The final adjustment of the quantity of oil is made according to the "zero adjustment" explained in a subsequent paragraph.

PREPARATION OF LIME FOR ABSORPTION CHAMBER.

In preparing the lime for the absorption chamber, about 1 hundred-weight of burned marble lime or good white lime is slaked in the following manner. After the larger pieces of lime have been broken they are placed in a basket and dipped for about half a minute in water. The resulting mass is then emptied into a flat box and covered over. After an interval of a few hours, examination is made to determine whether the lime has become pulverized; if not, the lime is sprayed with a small quantity of water and covered again. This process should be repeated until the mass falls into a powder. If lime that is already slaked is available, it can be used directly.

FILLING THE ABSORPTION CHAMBER.

The absorption chamber is filled with a mixture of excelsior and lime. The filling requires care and should be done by the same person each time renewal is necessary, in order to obtain uniform service from each chamber or jar. The excelsior is made thoroughly damp and a thin layer, less than one-half inch in thickness, is placed in the bottom of the jar rather loosely. Lime is scattered over this, then more excelsior added, and so on. The object, however, is not to have the two materials in layers but to have a jar full of a loose mixture of excelsior and lime. If, when the chamber is about full, it is pounded lightly on the table, the mixture will settle about as desired. Another thin layer of excelsior is put on top after the mixture has filled the jar. Before the cover is reclamped the rubber packing ring should be well cleaned and greased with a little vaseline. It is important to tighten the cover clamping screws as symmetrically as possible.

TEST FOR AIR LEAKS.

The chamber is connected in position and a test is made to insure that there are no air leaks. The gas cock *d* is closed and the air cock *l* is opened. The water tap *a* is then opened and the oil observed in the oil gages of the meters. The right-hand, or m_1 , gage should read very near zero; the left-hand gage should not fall much lower than 25. It may read higher. Should it fall lower the absorption chamber has been packed too tightly and, owing to the formation of water in the jar through the chemical action between the lime and the CO_2 , this draft may increase from day to day until the oil level drops out of sight. The air cock *l* is now closed, the oil in the gages

is allowed to fall about 30 mm., and the water tap is then closed. The gages come to rest somewhere in sight; if the apparatus is gas tight the oil levels will not change. If the levels rise perceptibly in a short time, there is a leakage to be traced, probably in some of the joints. This test for air leaks should be made whenever a new jar is placed in service.

Similarly, immediately after erection of the instrument the whole of the gas-pipe connection to the filter can be tested. The upper part of the soot filter should be removed and the pipe connecting to the flue should temporarily be plugged so as to make it air-tight. With the air cock *l* closed and the gas tap *d* open, the leakage test is again made.

ADJUSTMENT OF INSTRUMENT.

The instrument is now ready to be adjusted. The knurled screw at the top of the recording drum should be tightened by turning it clockwise. The drum should then be turned counterclockwise, thus winding the clock. As soon as the clock has been fully wound the knurled screw automatically loosens itself. The chart may now be set on the drum, care being taken that the bottom edge of the chart rests on the flange of the drum. When the pen points to the correct time on the chart the knurled head is screwed up. With the gas cock *d* closed and the air cock *l* open, the recorder is set in operation by opening the water cock *a*. The flow should cause large gas or air bubbles to appear without interruption in the water vessel *c*. In this condition the apparatus absorbs no CO_2 but records the slight difference in the speed of the two meters. This difference depends on the position of the air surfaces in the two meters, and is correct when the record lines on the chart are no longer than the free space below the zero line, or about 4 mm. If the marks are longer, a small quantity of oil must be added in meter m_2 , or some taken from m_1 ; if, on the other hand, the lines are very short, they will be lengthened if a small quantity of oil is taken out of meter m_2 or added to meter m_1 .

For running oil out of the meter, the small cocks fitted to the bottom of the meters are unscrewed. After the length of the lines has been so adjusted, the position of the recording pen is corrected by means of the adjusting screw *t*, in order that the upper ends of the record lines may average on the zero line of the chart. The recorder should be operated for about one hour. The gas cock *d* may then be opened and the air cock *l* closed. The recorder will now register the CO_2 content.

Throwing back the small lever at the right-hand side of the differential gear box *f* puts the recording pen out of gear. The pen should always be thrown out of gear when the instrument is not in use. From time to time the quantity of oil in both meters should be noted. The level in the right-hand gage will show the draft on the gas line.

SIMMANCE-ABADY CO₂ RECORDER. INSTRUMENT 2.

CYCLE OF OPERATIONS.

The Simmance-Abady CO₂ recorder is shown in figure 3. A presentation of the cycle of operations will explain its construction and the principles of its action.

The cycle of operations is as follows; the letters ascribed to parts referring to figure 3. Water from the reservoir *k*, having safety overflow *oo*, flows through the hollow valve stem *e*. In siphon tank *a* there is the weighted float *b*, which is attached by means of the chain *c* to the bell *d* of the extractor; the float rises with the water, allowing the bell *d* to fall. At the top of its stroke the float *b* raises the valve stem *e*, thus tripping the valve, and momentarily flushing the siphon tank; the water now siphons out of *a* through siphon tube *g*, allowing the weighted float *b* to fall. As it falls it draws up the water-sealed extractor bell *d*, in which is created a partial vacuum, and into which, therefore, gas flows from the flue through *p* and *h*.

Next, the weight of the water that has flowed from the siphon tube *g* into the small pot beneath it overcomes the weight of the counter *q* and closes the balance valve *h*, thereby cutting off a definite sample of the gas. Water is released from the small pot in time to allow the valve to open at the proper interval. The stream of water is continually flowing into the tank *a*, and the float *b* rises again, allowing the extractor bell *d* to sink. As it sinks, the gas in bell *d*, which, by the closing of valve *h* is now uninfluenced by vacuum or other conditions in the flue, is first reduced to atmospheric pressure, and is then under further pressure. The volume of gas is, therefore, forced

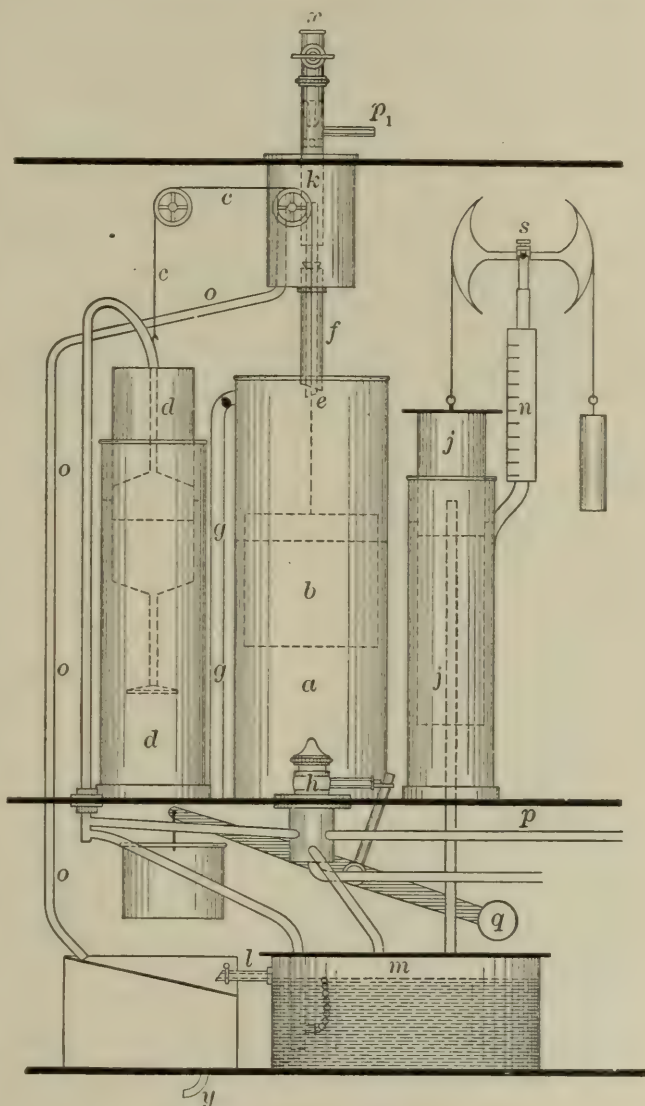


FIGURE 3.—Simmance-Abady CO₂ recorder.

into the caustic potash vessel *m*, where it bubbles up through the caustic potash and its CO_2 is absorbed; thence it passes into the recorder *j*, raising the bell.

The boxwood scale *n* at the side of the recorder tank is graduated to show 100 per cent CO_2 at the bottom and 0 per cent CO_2 at the top, and the capacity of the bell *d* is such that when the apparatus is run on air, containing practically no CO_2 , the total volume is transferred to the recorder bell *j*, which then rises to the zero point. When flue gas is admitted to the apparatus, exactly the same quantity, that is, enough to send the recorder bell up from 100 to 0, is passed from the extractor bell *d*, but on the passage of the gas, the CO_2 is absorbed by the caustic potash in the steel vessel *m*, reducing the volume of the gas; owing to such absorption the recorder bell *j* will not rise to its full height. It

will rise automatically to some point, and the pen will drop, registering its position on the chart.

The bell *j* then vents, discharging the analyzed gas through the balance valve *h* so that it does not mix with or come in contact with the fresh charge of gas, which is dealt with in exactly the same way, the whole operation, as well as the continuous drawing forward of the flue gas, taking place automatically by means of the stream of water. For the purpose of introducing a

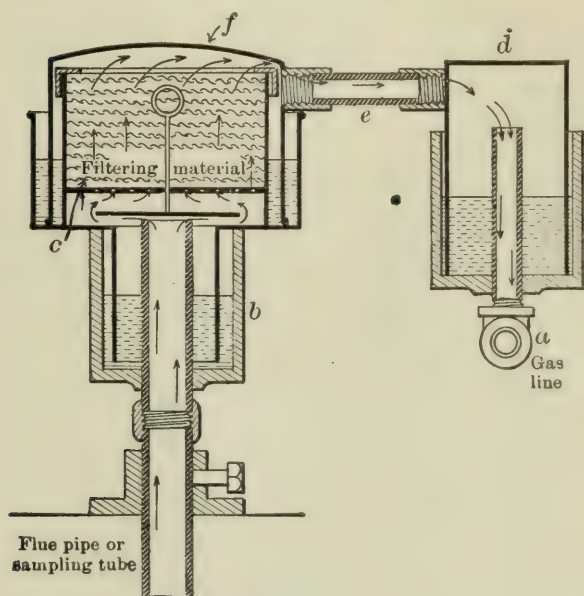


FIGURE 4.—Dust filter and connections, Simmance-Abady CO_2 recorder.

constant supply of gas, there is, below cock *x*, the injector or aspirator attached to the top of the case; p_1 is an auxiliary gas connection to the aspirator from the main inlet pipe *p*. By this means gas is continuously exhausted from the pipes connecting the recorder to the boilers.

Figures 15 and 16 show instrument 2 as installed for tests.

PLACING OF THE INSTRUMENT.

To avoid vibration the recorder should be placed upon a firm foundation, either a brick pier, about 24 inches wide by 20 inches deep by 30 inches high, or steel brackets attached to the wall. If the recorder is to take samples from a battery of boilers, it should preferably be placed about midway between the extreme ends of the battery, so as to shorten the maximum distance of travel of the gases. The distance between the recorder and the farthest sampling pipe should not exceed 200 feet. The place selected should be as free from temperature changes as possible.

DUST FILTER.

Figure 4 shows the filtering arrangement. A dust filter, *c*, with a cover, *f*, is provided. The filter cover and the cap *d* are connected by a length of gas pipe or armored hose, *e*. The filter *c* is set into the cup *b*, and light oil is poured into the channel in the filter in which the filter cover rests. The oil acts as a seal. The filter is then filled with filtering material (excelsior, cotton waste, etc.), not packed too tightly, and over this is placed a piece of light flannel which is held in place by a cast-iron ring. The filter cover is then placed on and sealed with oil. Only enough oil is used to make the seal and keep the connection air-tight. The level of the oil in the cups will be depressed by the vacuum in the flues, and if additional oil is poured in at this juncture, the oil is likely to flood the line. The gas passes through filter *c* and connection *e* to cap *d*, and thence to gas line *a*.

GAS AND WATER CONNECTIONS.

The gas line is brought down to the instrument, and connection is made at *p* (fig. 5) by a rubber tube *c*. Bottles *a* and *b* are telltales to show respectively

whether the flue-gas pipe is clear of obstructions and whether a constant stream of gas is maintained. Each bottle is fitted with a rubber stopper, through which extends a long and a short glass tube. The longer tube is sealed in bottle *a* with about 2 inches of water or light oil

and in *b* with about one-half inch. Water in *b* should bubble constantly and smartly to show that the gas is passing freely and that the injector is working; water in bottle *a* should bubble only when the gas piping becomes stopped, when the safety seal opens and air passes into the extractor bell through the longer tube. Figure 5 shows the exact arrangement of bottles that should be made. It is essential that there be no leak at the rubber stoppers.

The water that operates the recorder should be supplied under a constant head and should be clean. The water may be passed under city pressure through a water filter, which can be made of a length of gas pipe, placed vertically for ease of cleaning, with blank flanges at

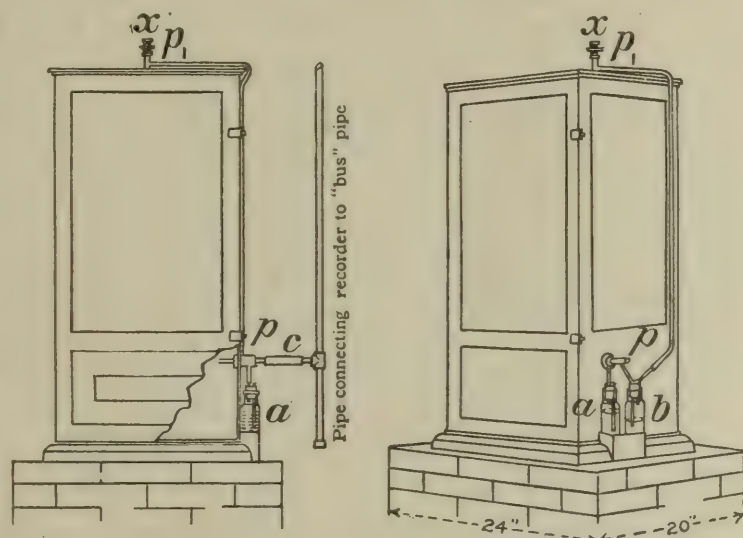


FIGURE 5.—Recorder case and gas and water connections, Simmance-Abady CO₂ recorder.

both ends, the bottom half of the piping being filled with coke and the upper half with sand, and the top covered by a piece of flannel. Such a filter is necessary only for very dirty water; for ordinary water a small filter is supplied. The water from the filter flows to a tank having a float valve, which may be an ordinary water-closet tank, and thence under constant head to the recorder.

The constant-level tank should be covered with a piece of canvas or a board so as to prevent dirt from falling in. Such dirt would obstruct the free passage of water and would in time get into the injector at the top of the recorder. The tank should be at least 6 feet above the recorder. The pipe through which the water flows from the tank to the recorder is quarter-inch wrought-iron pipe, which is screwed into the female end of the cock *x* (fig. 3) at the water inlet just above the filter pump on top of the apparatus. The water pipe should not be run near hot steam pipes, as hot water will raise the temperature inside the case of the recorder; the result would be to make the recorder sweat and cause the water to evaporate rapidly in the extractor and recorder tanks. A quarter-inch drain pipe for waste water is run to the sewer from the connection at the bottom of the case.

PREPARATION AND USE OF CAUSTIC POTASH SOLUTION.

After the recorder has been removed from the packing case and placed in position the first operation is to make the caustic solution and allow it to cool. The solution should be caustic potash (KOH), not caustic soda (NaOH), and is made by emptying the contents of one 2-pound KOH tin into the tin-lipped vessel provided and filling carefully with clean water up to the wire gage inside the vessel. When the solution has been allowed to cool to room temperature it should be placed in the steel KOH tank and stirred well to dissolve the caustic. More KOH can be used, and the solution will last much longer; the specific gravity may be 1.27. A small glass funnel is provided with which the KOH solution can be poured through rubber tubing into the center nipple of the cylindrical steel tank *m* (fig. 3), the pinch cock on the overflow tube *l* being kept open. If the tank is standing on a level table, the excess will obviously run out through the overflow tube, thus giving an absolute level. The pinch cock should be closed carefully so that tank will be air-tight. The caustic potash solution is corrosive, and it should not be allowed to come in contact with the hands or clothes nor any part of the apparatus other than the vessel *m*. The shelf of the recorder should be level.

SETTING UP THE RECORDER.

Figure 3 shows clearly the position of the various parts. Directions for assembling the parts are as follows: Screw the filter pump containing injector into the threaded connection inside the overflow tank

k as far as the thread will allow or until the lower end of the filter pump is submerged. Fill tanks *d* and *j* with clean water to overflow, placing wide-mouth bottle under overflow pipes.

Run some water into siphon tank *a* and drop float *b* into siphon tank. Connect chain on float to small gold-plated chain *c* and run over pulleys to hook on extractor bell *d*.

Hang balance arm *s* on its fine-point bearings in the grooved cradle, being careful that the weighted adjusting arm extends to the right. Attach fine chain from segment of balance arm to hook on recorder bell *j*; then hang brass counterweight on opposite end of balance arm.

Attach striker lever *q* with bucket to pin under shelf so that the upright arm on the striker lever will engage yoke on lever of cock *h*. Note that yoke does not strike siphon tank and that *q* does not strike nut attaching recorder tank to shelf.

Make rubber connections as shown in figure 3, being careful that there are no kinks in the rubber tubing. If the rubber becomes worn or seems loose, paint with asphaltum paint.

Vaseline is thinly smeared on the ground face of the balance valve *h*. Lubrication once a week is generally sufficient. The ports in the valve and its socket should not be obstructed with vaseline, as this will hinder the passage of the gas.

Now place a chart on the clock disk, being sure that the center point on the disk passes through the center of the chart. It may be necessary to punch a hole with a pin in the center of the chart before placing the chart. The clock and pen levers are now placed in position. The pen fittings consist of two distinct sets of parts, first the pen proper with its brass arm and screw counterbalance weight, and, second, the black bronzed actuating lever with its weight suspended by a chain. The screw counterbalance weight of the pen is adjusted so that the end fitted with the hanging weight is slightly the heavier, and so that when the support of the actuating lever is withdrawn the hanging weight is free to descend until it touches the disk of the recorder bell; when in position the weight is held up and kept there by the projecting end of the black actuating lever, which, when in its socket, is about at right angles to the pen arm. The black arm with weight suspended by chain is fitted in the pillar, which is over the back or siphon tank *a*, so that the weight hangs over the tank, and can thus be lifted by the rising of the float *b* in the tank, and the pen arm released. The pen thus descends at the last moment of the stroke of the analyzer bell, so as to allow for the dispersion of the heat generated by the combination of the CO_2 with the KOH . Put the pen on its fine points into the grooved cradle provided, and see that the black arm mentioned is under the pen arm and supporting it.

The pen arm should be of such a length that the pen point will swing over the exact center of the chart. When the pen is at rest see that the levers rest lightly on the ends of the adjusting screws, and that there is no play between the ends of these screws and the lever arms, the pen movement being held rigidly in place. This adjustment becomes at once apparent when the pen mechanism is hung in place. See that the point of the pen on this rest position stands about three-sixteenths to one-fourth inch to the right of or below the zero line; that is, about -2 per cent on the chart. The adjusting screws can be lowered or raised to make this adjustment.

FINAL ADJUSTMENT OF INSTRUMENT.

The final adjustment of the instrument can now be made. The water is turned on with such a pressure that the machine records its maximum number of records per hour—about 16 or 17. Greater pressure will prevent the siphon from stopping, and the cycle will never be made. As all connections have been made, the instrument will now be running on the flue gas. The first stroke will create the proper levels in the tanks, the excess flowing in the bottles provided. Note the temperature and the draft as recorded in the telltale bottle. This draft will represent the average draft, and the temperature should be an average one. Bell jar *j* (fig. 3) will be rising to some point on the boxwood scale, but not up to the zero mark.

See that the pen point registers on the chart the exact point where the edge of the jar is registering on the boxwood scale. Adjust entirely by means of the small brass nut that strikes the jar. Stop the instrument, if necessary, at the point in the cycle when the pen is registering so that it can be ascertained that the jar and pen are registering the same at any moment when the striker rod is resting on the jar. Disconnect rubber joint *c* (fig. 5), throwing the instrument on air. While the instrument is running, by means of an adjustable pinchcock, slowly close *c* until the telltale bottle shows the same draft as when running on flue gas. The pen (and jar) should register zero at the end of each analysis. If not, adjust by means of the weighted adjusting arm on balance arm *s* (fig. 3). Twisting away from the fulcrum will cause the jar to rise higher.

After all adjustments have been made, operate the instrument for about 30 minutes, being careful to see that the telltale bottle registers the proper draft, which may require careful adjustment. Next, remove the pinchcock from the connection *c* (fig. 5). The telltale bottle will now show no draft. Operate for another 30 minutes and note where the pen registers. It will be somewhere below zero, depending on the amount of original draft. Afterwards, to check the zero point the instrument can be thrown on air at no draft and made to register this minus point as found. It is well to check this

point every few days and particularly when there is much temperature change. The instrument can now be thrown on the flue gas for continuous running.

MISCELLANEOUS INSTRUCTIONS.

Wind the clock every week. It runs for eight days. Do not overwind. The clock is regulated before being sent out, and can be kept in adjustment by the regulator in the usual manner.

Every morning fill up the tanks with water to make up for evaporation, allowing the excess to flow out as before. In a later type, an automatic arrangement for keeping these levels constant is in use. Unless a maximum of two drops per cycle and exactly the same amount of water per cycle can be made to flow by the adjustment valve, the other method would better be used, as this flow affects the reading.

Every morning open pinchcock *l* (fig. 3) to keep the KOH level constant, as water forms from the chemical action involved, raising the level continually.

If the chart curls, leave the doors open slightly. Watch the condition of the joint of the cover on the KOH tank, which may leak. This will cause the instrument to read high.

“SARCO” AUTOMATIC COMBUSTION (CO_2) RECORDER. INSTRUMENT 3.

DESCRIPTION OF OPERATION OF INSTRUMENT.

For the “Sarco” automatic combustion (CO_2) recorder the power required is derived from a fine stream of water at a head of about 2 feet. The water enters the instrument at 8 (fig. 6) through the small glass injector 9. Of the latter several are provided, having apertures of different sizes, and by using different sizes the speed of the machine may be adjusted at will.

The water flows through tube 74 into the power vessel 82; here it compresses the air above the water level, and the pressure is transmitted to vessel 87 through tube 78. The pressure thus brought to bear on the surface of the liquid with which vessel 87 is filled to mark 95 sends the liquid upward through tubes 91 and 93.

Thence it passes up into vessels 77, 66, 68, and 67, and into tubes 51, 52, and 49. It rises until it reaches the zero mark 71, on the narrow neck of vessel 67. At the moment it reaches this mark the power water, which, simultaneously with rising in vessel 74, has also traveled upward in siphon 72, will have reached the top of this siphon, which then begins to operate.

Through siphon 72 a much larger quantity of water is disposed of than flows in through injector 9, so that the power vessels 74 and 82 are rapidly emptied.

The moment the pressure on vessel 87 is thus released, the liquids return from their respective tubes into this vessel.

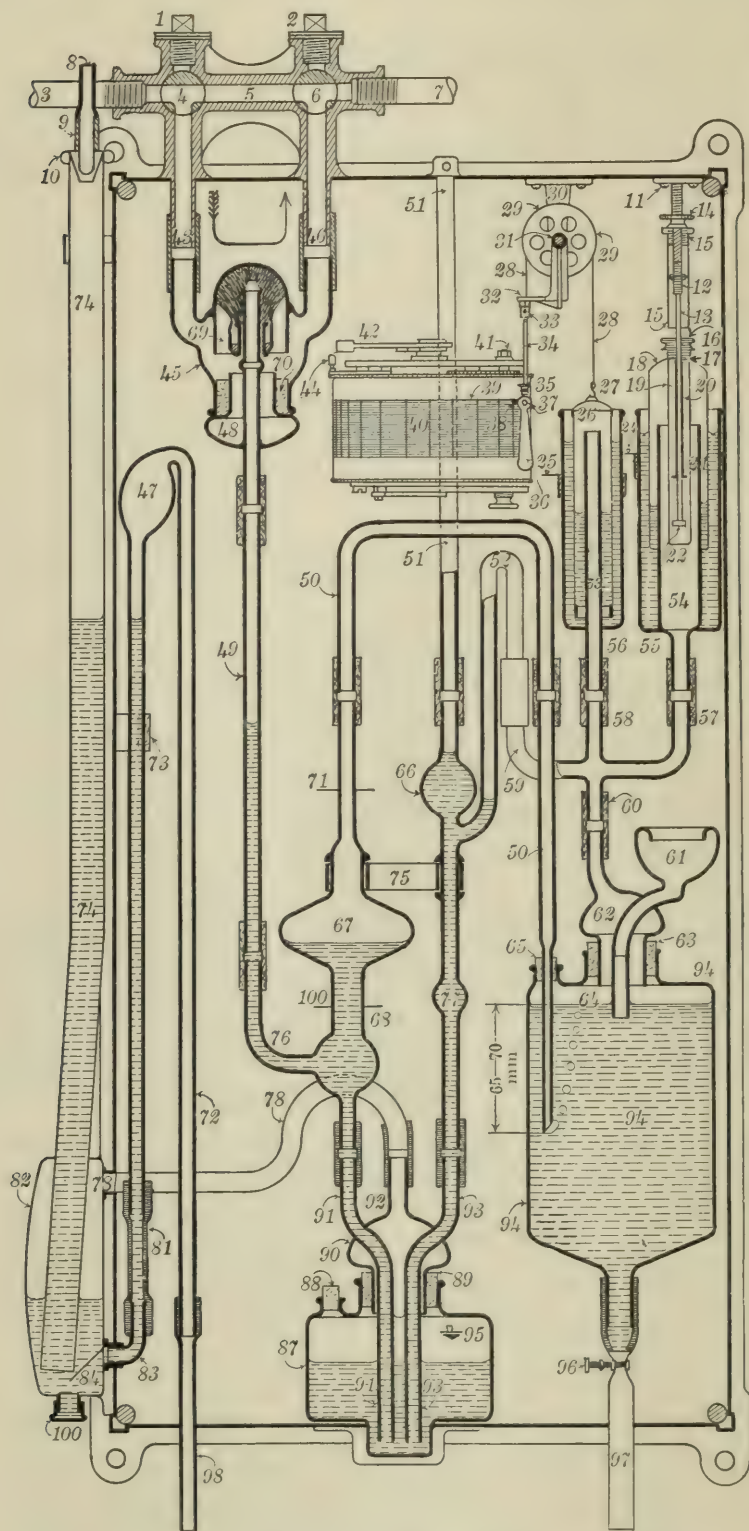
Tube 49 is assumed to be in connection with a supply of flue gas; a sample of the gas is drawn from the continuous stream that passes through 43, 45, and 46, as the liquid recedes in 49, by the partial vacuum created by the falling of the fluid.

As soon as the liquid has dropped below point 76, which is the inlet of the flue gas into vessel 67, the gas rushes into this vessel and its connections.

As soon as the flow in the siphon stops, vessel 82 begins to fill again, and the liquids in tubes 91 and 93 rise afresh. The gas in 67 and 68 is now forced into tube 50, and caused to bubble through a solution of caustic potash (specific gravity 1.27) with which vessel 94 is filled to point 64, marked on the outside.

FIGURE 6.—Parts and connections of Sarco automatic combustion (CO_2) recorder.

In this process any CO_2 that may be contained in the gas is readily absorbed by the potash. As the gas has to pass through the potash, the absorption is rapid and complete.



The remaining part of the sample collects in 62, and passes up through 60 into tubes 57 and 58. It can not pass out at 59, as this outlet is sealed by the liquid in 52.

The gas now passes under the two floats 18 and 26. As float 18 is larger and lighter, it will be raised first.

By turning the thumbscrews 14 and 15, the stroke of this float is adjusted until just 20 per cent of the whole of the sample remains to raise float 26, when nothing is absorbed in 94, as would be the case if air is passed through the recorder.

The latter float has attached to it pen 36, which is caused to travel downward on the chart when 26 rises.

If no CO_2 were contained in the gas, nothing would be absorbed by the potash in 94, and the whole of the 20 per cent part would reach float 26. Thus the pen would be caused to travel the whole depth of the chart from the 20 per cent line at the top to the zero line at the bottom. Any CO_2 gas contained in the sample would be absorbed by the potash, a correspondingly less quantity would reach float 26, and pen 36 would not travel to the bottom of the chart, that is, the zero line.

Thus any CO_2 absorbed will be indicated by the length of the lines on the chart.

On the return stroke of the liquid, the gas is drawn from under floats 18 and 26 through tubes 57 and 58, and into tubes 59 and 52. From here it passes out into the atmosphere at 66, and through tube 51, as soon as the liquid has fallen below the outlet of tube 52.

Figures 15 and 16 show instrument 3 as installed for making the tests.

DETAILS REGARDING INSTALLATION.

The position selected for the recorder should not be exposed to great heat or strong drafts. The temperature should be as even as possible and there should be no vibration.

The filter provided with each machine is inserted into the $\frac{3}{4}$ -inch main pipe as close to the boiler as possible. In this position it will keep a maximum part of the pipe system free from soot. The interior of the filter is filled with excelsior or horsehair, which must not be packed tightly, but may be intersected by $\frac{1}{2}$ -inch layers of sawdust if the gases are very dirty. The lid dips into a seal of heavy oil or glycerin, which must be kept to the level of the overflow to prevent air from being sucked into the pipe system. The filter is provided with two three-way cocks which control the inlets and outlets so that the line can be shunted through a by-pass pipe, completely cutting off the filter. This is to enable the cleaning out of the pipe to free it from soot by means of steam or air. The lower part of the filter forms a collector for condensed moisture, and

should be emptied from time to time by removing the plug at the bottom. An automatic drain is fitted when specially required.

The gas line is brought to the recorder and the final connection is made by a union and a piece of half-inch pipe. A second pipe of three-fourth inch (or, in exceptional cases, 1 inch) internal diameter is tapped into the base of the chimney or into the main flue, well beyond the dampers, thus creating a complete by-pass of gases from the boilers through the recorder and into the chimney. This pipe should also be provided with a fall towards the recorder, and a vertical drain pipe with cock should be fitted, the connection to the recorder being made again by a union and $\frac{1}{2}$ -inch piping. The matter of a constant flow through this line is of vital importance, and the exact draft on the two sides of the recorder should always be ascertained before the final connections are made. There should not be less than $\frac{1}{4}$ -inch difference in favor of the chimney side, measured when the pipe system is complete and the filter in circuit and ready for use. If sufficient difference of draft is not obtainable the suction through the recorder must be induced by other suitable means such as a connection to the suction side of a fan, or an insertion of an air, steam, or water injector into the chimney pipe. A small U-tube indicator can be put in parallel with the instrument to show at any time the difference of draft available and also to indicate when the pipe line requires cleaning. The instrument can, by three-way cocks, be by-passed to leave an open line for cleaning.

The operation of the apparatus requires some 3 to 5 gallons of water per hour. The water should be clean and of uniform temperature and pressure. It is preferably supplied by means of a small tank fitted with a float valve and about 2 or 3 feet above the top of the recorder. The level of the water in the tank must be kept uniform. The connection to the little glass aspirator 9 (fig. 6) supplied with the machine is made with a small piece of rubber tubing. With each recorder are sent a number of aspirators with holes of varying sizes, which determine the speed of the instrument. If the water contains impurities the tank should not be set much above the instrument, so that with a low head the size of the aspirator can be large and the aspirator will not tend to clog frequently. The waste pipe should be of 1-inch diameter and must have an open end, preferably funnel-shaped, to receive the water from the recorder. A pipe should also be provided for draining the potash tank.

SETTING UP OF THE INSTRUMENT PROPER.

When all the piping is complete to the point where the recorder is to be erected, the latter is hung on the wall by means of strong hooks or clamps. The recorder must be carefully leveled by the use of the small circular spirit level fixed in the machine, to insure proper

working of the pen. One of the glass injector nozzles 9 is selected and attached to the small piece of tubing 8 sent loose with the recorder, the other end of the tube being connected to the $\frac{1}{4}$ -inch water-supply pipe from the tank. The larger float chamber 55 is filled with pure liquid paraffin (specific gravity 0.86) to the top of the brass clip 24. The paraffin will injure the rubber and must not be spilled on it. In case any has been spilled the tube should be wiped perfectly dry. Then the aluminum float should be inserted carefully, the end of rod 13 being screwed into the socket 11 and locked there by means of nut 12.

The float should not be dented or damaged, and nuts 16 and 17 should be tight. Collar 15 with its lock nut 14 should be brought to about the position shown in figure 6. The smaller float chamber 56 should also be filled with paraffin to the top of clip 25, and the brass float 26 inserted. The cotton thread to which the pen gear is attached should be placed over the pulley 29, and hook 27 fixed to the float. The length of the thread is so adjusted that the float is about one-fourth inch from the bottom of the vessel when the pen rests against stop 32. The pen should be given a number of twists away from the chart; the torque will then keep it against the paper. This twisting also shortens the length of the thread, thus raising the float, a detail that must be considered when adjusting the length of the thread. Smooth thread must be used as thread that is the least uneven will cause the pen to make a crooked line owing to jerky movement over the brass wheel 29.

INSTRUCTIONS REGARDING RECORDING PARTS.

In setting up the recording part proper the following instructions should be observed:

Wind the clock, paste one of the charts together and slip it over the clock drums from below, bringing the drums together by moving lever 44 to the right and then letting it slide back gently. Set the chart by sliding it so that the pen points to the time of day. Adjust the length of rod 33 until the point of the pen rests exactly on the 20 per cent line. Fill the container with ink through hole 37. Assist the passage of this to the pen by removing the latter and passing the wire provided through tube 38. Moisten also the lips of the pen with ink. If the line produced is too fine, open the lips very carefully by the use of the fine blade, only sufficiently, however, to be just perceptible. Mix one part of the glycerin accompanying the instrument with three parts of water, and fill vessel 87 nearly full, or to point 95 indicated in figure 6. Dissolve in a strong earthenware or glass jar all the potash sent with the recorder, using 43 ounces of water, preferably distilled. Pour in the water and add the potash gradually, a few sticks at a time, stirring the solution. It becomes

hot while the potash is dissolving and must be allowed to cool before it is poured through funnel 61 into vessel 94. The latter should be filled exactly to the little glass projection 64 on the lower end of the funnel tube. If too much has been added, the excess should be drained off by opening clip 96. The specific gravity of any solution prepared subsequently should be 1.27.

FINAL ADJUSTMENTS.

Instructions as to the final adjustments of the instrument are as follows:

Take out plugs 1 and 2, setting cocks 4 and 6 to cut off the line and let in air. The temperature of the instrument must be that at which it will be operated; if the temperature changes from day to night, the instrument should be set for the average temperature.

Turn on the water through nozzle 9 into tube 74. As the water rises in 82 it will compress the air above the water level and through tube 78. This pressure will act on the liquid in 87, forcing it up tubes 91 and 93. The liquid should rise exactly to zero mark 71 on the neck of measuring tube 67, that mark being reached at the moment when the water in siphon 72 reaches the top and the siphon begins to operate. Should the liquid go higher or lower, adjust the position of siphon 72 after slackening clip 73. Raising the siphon will cause the liquid in 67 to travel higher, and vice versa.

Adjust until the average is at mark 71. In making this adjustment care must be taken not to raise the siphon so high as to force the liquid over through elbow 50 into the potash solution, as that would be spoiled. See that the point of the pen stops exactly at zero on the diagram at the moment the liquid reverses. If not, adjust collar 15; to lower the collar will cause the pen to descend farther, as more of the gas will be apportioned to the brass bell, causing it to rise higher.

About 30 records per hour can be taken. It is not desirable to exceed this speed as the CO_2 will then pass through the KOH too fast, especially when the solution is becoming weak; moreover the liquid piston tends to form more bubbles. Too slow a speed is also undesirable as the liquid forced up from 87 then rises too jerkily, and its levels do not average so well at the time of siphoning. The instrument should be running at the same speed when it is adjusted as when in service.

When adjusting see that, as the liquid rises in 77, no bubble precedes the level, as this will cause the pen to travel down too far. Such bubbles sometimes occur when the glycerin solution gets heavy after some months of use, and the bubbles do not break well at 77. See that 66 is held in place by 75; its action can be checked by seeing that 52 is closed by the rising liquid in 77 at the instant the level in

67 is at the mark 100 on that vessel. Operate for about one hour after all adjustments have been made.

The recorder can now be connected to the gas line. Examine all rubber connections to see that there is no possibility of leakage. Painting all rubber joints and stoppers with asphaltum paint will doubly insure against leakage. In the latest machines the stirrup (43, 45, 46) has been developed into a filter to prevent particles of soot entering the recorder.

The filter is charged with glass wool, which must be taken out occasionally and washed. Wind the clock daily and keep the pen filled with ink. The levels of the different liquids should be watched carefully. The KOH solution forms water in reacting with CO_2 , so that the level of the solution rises a little each day. The higher level affects the reading, and unless the level is at 64 the recorder will not register correctly. The level should be adjusted daily. Add water to the glycerin solution when it gets low in 87. Keep the paraffin about the bell jars at the same level as when the zero was adjusted.

THE "TELEZOMETER" CO_2 RECORDER. INSTRUMENT 4.

DESCRIPTION OF RECORDER.

The "Telezometer" CO_2 recorder is described with reference to figures 7 and 8. In figure 7, *e* and *f* represent two centrifugal fans driven by the constant-speed electric motor *g*. Fan *f* draws in surrounding air through inlet *h* and forces it out through outlet *k*; fan *e* draws in flue gas through inlet pipe *m* and forces it out through outlet *j*. There exists, therefore, a difference of pressure between *h* and *k* and between *m* and *j*. These differences of pressure vary with the density of the fluid medium. As the CO_2 component of flue gas is much heavier than any other constituent, the density of the flue gas varies with its CO_2 content. Referring to figure 8, the movement of the lever *w* is caused by the resultant of the four static pressures, *m*, *j*, *k*, and *h*, acting on the bell jars arranged as shown. The movement of this lever is recorded by the pen *t* on the clock chart *x* in percentages of CO_2 .

In figure 8 the bell jars 1, 2, 3, and 4 are represented as floating in separate vessels, whereas in reality 1 and 2 float in one tank and 3 and 4 in another. The regulation of the inlet and outlet pressures of the air fan *f* is accomplished by means of the pin valve at *h*, figure 7. Through this regulation the instrument can be adjusted to its zero position when both fans are circulating air. Paraffin oil used in the two tanks is shown at *y*.

The remaining parts of the apparatus are shown in figure 7, as follows: *a*, gas filter; *o*, *o'*, drains from the two tanks in which the

bell jars float; p, p' , overflows for these tanks; r , manometer inserted in the line m for special purposes in testing; d , special gage showing the difference of pressure between h and k , used only for testing purposes; n , electric line to motor; c , case containing tanks and recording mechanism; z , lead connecting tubing.

Because of the difficulty of maintaining the necessary operating conditions in service no instructions regarding the erection and operation of this machine are given herein.

Figure 15 shows instrument 4 as installed for the tests.

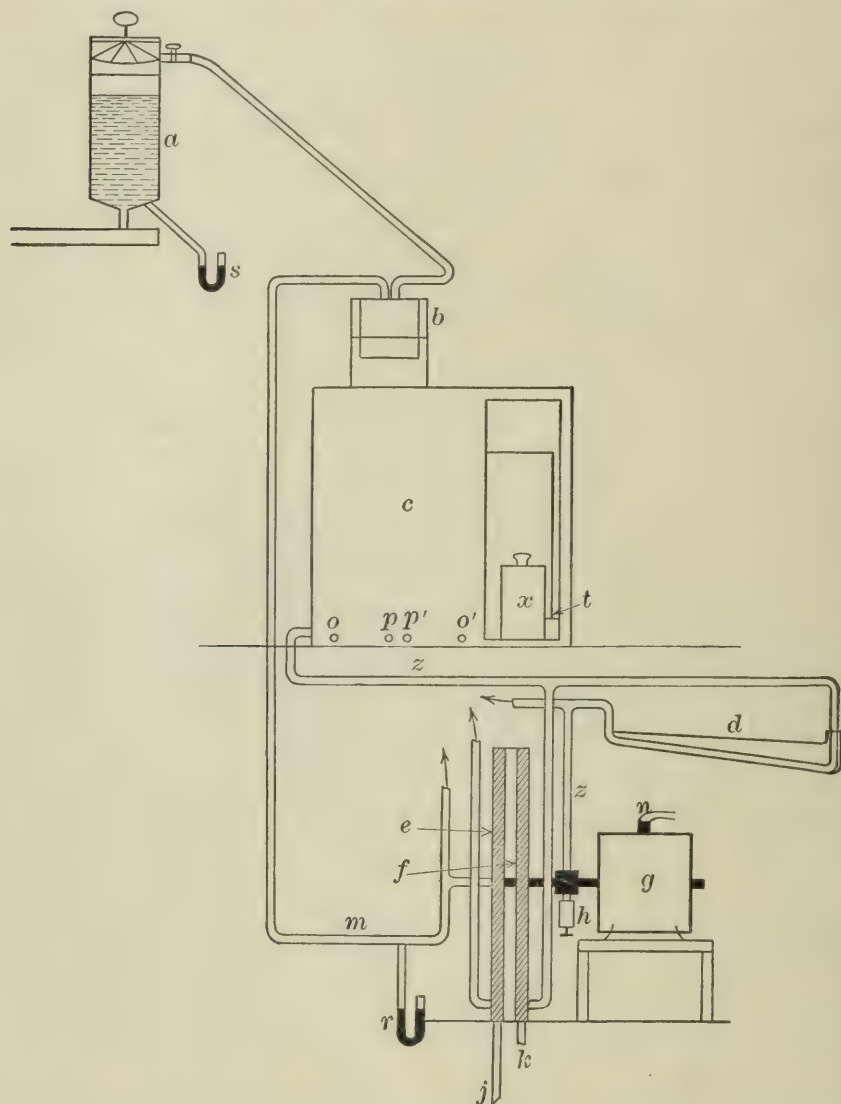


FIGURE 7.—Arrangement of parts and connections of "Telezometer" CO₂ recorder.

UEHLING CO₂ MACHINE. INSTRUMENT 5.

DESCRIPTION.

The Uehling CO₂ machine may be explained by reference to figures 9 and 10, in which the letters and numbers correspond. The instrument is really an open pipe line in which pressures (below atmospheric) are measured at different points. The line has been given its present shape for the sake of compactness. If suction is

created by any means at C'' (fig. 9), gas will tend to flow through the line, entering at filter D . At manometer M the pressure on the line is measured. The gas passes through valve J , and the pressure is measured again at S . Here it meets an auxilliary suction, C , and tends to divide, the division depending on the relative suction.

Thence the gas passes through valve 2, through the small cotton filter F , through the steam pot X where it is heated to a constant temperature and then meets a high resistance in the form of the orifice A . The gas next passes through the caustic N , after which the pressure in the line is again measured, this time by L , G , and P , being the water scale at the front of the instrument, the boiler-room in-

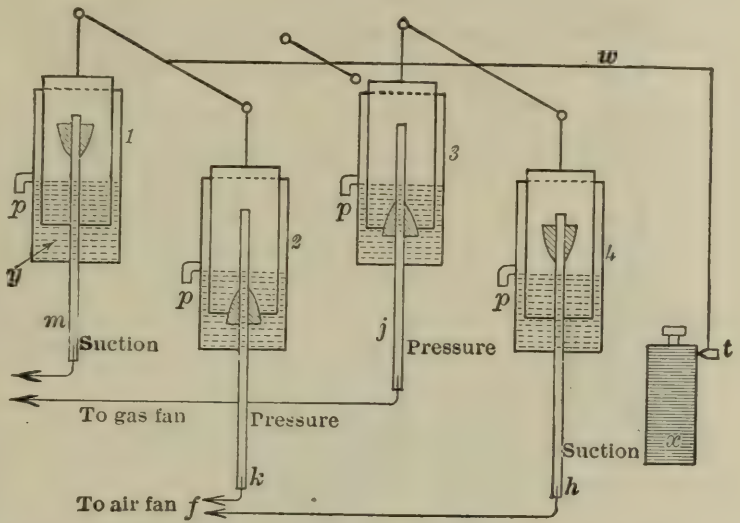


FIGURE 8.—Arrangement of bell jars and connections, "Telezometer" CO_2 recorder.

dicator, and the chart recording gage, each measures pressure. The gas now passes through another small cotton filter F' , again through the steam pot X , where it assumes again its original constant temperature, then meets another high resistance at orifice B . Finally it passes through valve 4 out through the suction.

The method of obtaining the suction C and C'' can be seen from figure 10. If valves 8 (to let in air), J , 2, and 4 are open and valve 5 is slowly opened, a suction is produced, and atmospheric pressure

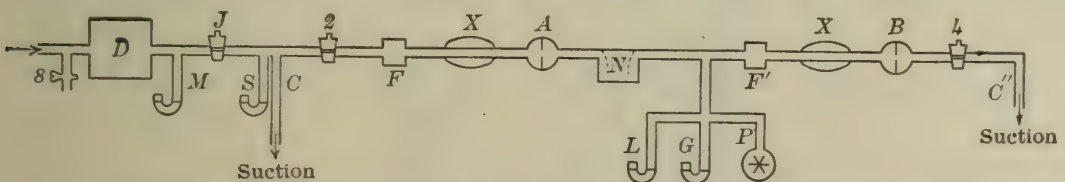


FIGURE 9.—Diagram of essential parts of Uehling CO_2 machine, arranged as a train.

on the water in H is lowered. As the suction becomes great enough, air flows in through the center tube a and relieves the suction. At the same time air flows in through the line, owing to the suction C and C'' . The pressure of the suction is registered by tube v . Now if manometer S is held constant by valve 5, a certain flow of gas is induced through the recording line; and the gas is kept at a constant temperature by being heated at two points just before it passes

through its highest resistance. L , G , and P will be registering a pressure varying between C and C'' , depending on the resistance on either side. If, for any reason, L shows a higher level at one time than another, the indication is that the pressure is nearer to C'' , that is, that the resistance at A or F or N has increased; if L shows a lower level at one time than at another, the resistance F' or B has

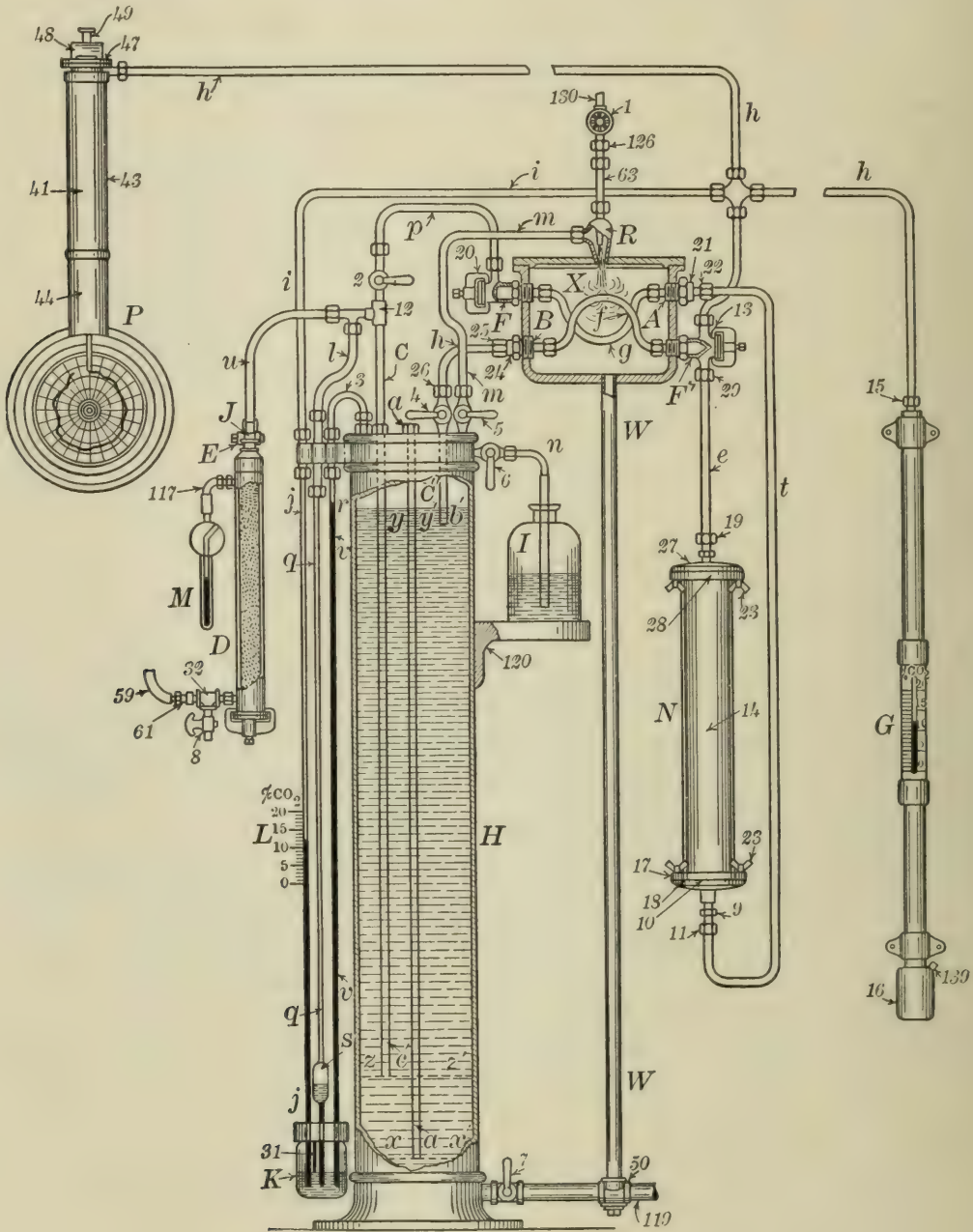


FIGURE 10.—Actual arrangement of parts and connections of Uehling CO₂ machine.

increased. If gas containing CO₂ now flows through the line it will give up part of its volume at N . This condition could be considered as the resistance between L and C'' being decreased, so that the level of the liquid at L will be higher. And so it is necessary only to mark on a scale at L , G , or P the level of the liquid for a gas of a known CO₂ content.

ADJUSTING THE WATER LEVELS.

The various water levels are now ready to be adjusted. See that the recording line is cut off by closing 4 and 2. Have *J* and 8 open. Turn on steam through the aspirator *R* by means of valve 1; see that valve 55 (fig. 11) is giving off vapor. Now open valve 5 (fig. 10) slowly until manometer *S* registers at the pointer. A slight bubbling noise will be heard in *H*, and the level of the water in manometer *v* will be somewhere below mark *r*. This level should be raised until it is about one-half inch above mark *r*, by letting more water be sucked through valve 6, from jar *I*. This raises the head on relief tube *a*, and level *r* comes up. If too much water runs in, valve 7 should be opened and the water let out through the drain. If the water is let out, the steam should be shut off.

Now open cocks 4 and 2. *L*, *G*, and *P* will register somewhere near zero. Fill *K* until the bottom of the rod 31 is just touching the water. Now check *v* and *S*. Before adjusting for zero, the instrument must be tested for leaks. By closing valve 2 the pressure in the line is much reduced, and the level at *L* climbs up; when it reaches a point about 6 inches above the 20 per cent line, close cock 4. Let the levels of *L*, *G*, and *P* come to a standstill. They should remain there unless there is a leak in the instrument. If the levels will stand at the 15 per cent line for several minutes, the adjustment is satisfactory for practical working.

TESTING FOR LEAKS.

If a leak is indicated, it will probably be in the connections made when setting up. These should be gone over carefully. Each unit can be tested for leaks independently if necessary. A leak is most likely to occur in the joints of the absorption chamber *N* which holds the caustic carton. Before looking elsewhere for a leak, make sure that absorber *N* is properly placed, and that the rubber rings are in their proper position. All connections are of drawn-copper tubing with a soft-copper flange and brass nut on each end. Connection is made with a hard-brass knife-edge surface which cuts into the soft copper, thereby making a joint absolutely tight. If, for any reason a connection is taken apart, care must be taken that the knife edge fits into the same groove that was made in the copper flange when connection was first made.

To blank off the boiler-room gage, disconnect near filter *F'*. Close the opening made by the removal of the tubing by a copper blanking disk and nut. Try the machine again for leaks. To test the indicator alone, disconnect the tubing at 15 and place the tubing in the mouth. Suck up the column of oil until it reaches the 20 per cent line, and close the opening with the tongue. If the column stands steadily the leak is in the tubing or connections; if not, the leak is in

the indicator itself in the joint between top piece 15 and the glass tube. This top piece with glass tube can be removed by loosening the set screw. The joint between the glass tube and the top piece is made by means of a rubber gasket on the glass tube with a washer and nut. In the same manner the recording gage can be blanked off.

To test the recorder alone, disconnect the tubing at the top of the recorder. Screw off the recorder name plate. Through the opening in front lift up the counterweight until the pen point reaches the 20 per cent line. Close the opening at the top of the gage. The pen should not sink. The most likely leak is about cap 47. If there is reason to believe that the leak is in the machine proper, go over the line carefully, tightening up connections, caps, etc. There is small chance for a leaky valve, but should a valve leak, the leak can be stopped with a little vaseline. To make sure that the leak is not in the absorber *N*, disconnect copper tube *t*, blank off the bottom connection of the absorber *N* with nut and disk and test for the leak in the ordinary way. In this manner and by ways that easily suggest themselves a leak can be traced and fixed. Asphaltum paint can be used to good advantage in many places. Not much trouble should be experienced from leaks.

ADJUSTING FOR ZERO.

To adjust for zero, the following method should be used. Let the machine run on air for about 15 minutes. See that the levels in *S*, *v*, and *K* are correct. If it is necessary, lift the pen of the recording gage to raise the float from its seat, to which the float sometimes sticks. The chart, the boiler-room gage, and the instrument gage should read somewhere near zero. Close valve 4 for an instant, long enough to allow the liquid in water gage *L* to drop one-half inch; then open again and let the liquids in all gages come to rest. Note their positions, and repeat a few times. Let them stand 10 minutes, then move the scale on the instrument to make its zero point at the water level in *L*, slide the small pen of gage *P* on its support so that it will register correctly, and adjust the boiler-room gage by twisting 16. The oil moves rather slowly and it may take some time to adjust 16.

The instrument can now be thrown on the gas by closing 8, and the CO₂ content can be registered. Manometer tube *M* shows the suction on the gas line. It should not go over 1½ inches. Too great a suction is probably due to filter 125 (fig. 12) being clogged. If the gas line becomes clogged the tube will bubble, thus relieving the line. In continuous running the condition of the carton *N* (fig. 10) can be told by the position of the zone of highest temperature upon it. CO₂ combines with KOH with an evolution of heat, and this heat zone in a fresh carton will be at the bottom where the gas enters. As the caustic is used up the zone of reaction or the heat zone moves

up. The heat zone can easily be followed with the hand, unless the room is cool and the percentage of CO_2 is low, and when the zone gets to the top the carton is used up. In stopping the machine close 5 ahead of 1, as otherwise the steam may condense and be sucked into *H*, thereby raising the water level in *H*.

MISCELLANEOUS DIRECTIONS.

Wind the clock daily. Filter 125 (fig. 12) should be replaced as necessary, depending on the condition of the flue gas sampled. If there is any discrepancy between the indication of the recording gage and that of the water column at *L*, a discrepancy most apt to occur when the CO_2 content is between 10 and 15 per cent, it will be necessary to set the gage at these points, correcting for the difference, rather than at zero. The difference will not involve an indication of more than 0.5 per cent CO_2 .

After some time of continuous running, differences in indications may appear. If the water level in bulb *S* (fig. 10) is high, make sure that the water level in *K* is right. Adjust valve 5, making sure that the suction in *v* is not broken by closing 5 too much. If the level in bulb *S* is still high, take out core of cock *J* and make sure aperture *E* is clean. If cleaning aperture *E* does not bring the 6-inch suction in *S* down to the index, then the cotton in filter *D* may be packed too tightly or may have gotten wet from the water in the U-bulb *M*. To clean filter *D*, open it at the bottom. When clean cotton is replaced, be sure that it is put in loosely. In replacing the cap be sure that a tight joint is made by means of a rubber gasket. If the suction bulb is low after adjusting valve 5, make sure that the core of the cock *J* is not loose and that the connecting points of copper tubes *u* and *l* are tight.

Each time a new carton is inserted test for leaks and adjust for zero as described. The cartons have different resistances and each new carton may change the zero adjustment slightly. Also in course of time the zero may get so high as not to be reached by the sliding scale. The variation is due to aperture *A* or filter *F* getting clogged. Change the cotton in filter *F* and make a good joint when replacing the cap. If the zero is still high, take out aperture *A*. Break the connection between tube *t* and 22 and screw out the nut, when the aperture holder can be pulled out. Hold the aperture piece under a jet of dry clean steam such as would issue from the full pressure line through a pet cock. A pet cock for this purpose should be put up permanently in some convenient place. The aperture piece can be held by means of a clean pair of pliers. Allow steam to play on the platinum center of the aperture piece for 15 to 20 seconds on each side. Do not touch the tiny hole with anything, as around its edges is a selvage that may be bent over, thus changing the size of the orifice. The piece should

be held no farther than an inch or two from the nozzle of the pet cock.

Replace the aperture piece in the holder in its original position. See that it fits in the holder just tight enough so as not to fall out when the holder is turned over. After several replacements the copper may bulge, owing to the pressure, and may become too tight in the holder. It then can be filed down. When replacing the holder, make sure that the steel key on its surface will be in line with the groove for it in the casting. Push the holder into place and tighten the nut. The

joint is made tight by the knife edges of the holder and the casting, which embed themselves into the copper of the aperture piece; hence the nut should carefully be set tight.

Figure 16 shows instrument 5 installed for the tests.

SETTING UP THE INSTRUMENT.

The instrument must stand firmly and should be at least 18 inches from the wall and so placed that the scale can be easily observed (fig. 11). The condensing filter should be fastened by means of a bracket to the side of the boiler or elsewhere in a position where the bell 89 (fig. 12) can be easily reached. A $\frac{1}{2}$ -inch water pipe, 128, must be connected as shown in figure 12 and should be supplied with a valve, 72. Tee 78 should be connected with a drain by means of a $\frac{3}{4}$ -inch iron pipe, 134. The drain should be led to a place where the outflow-

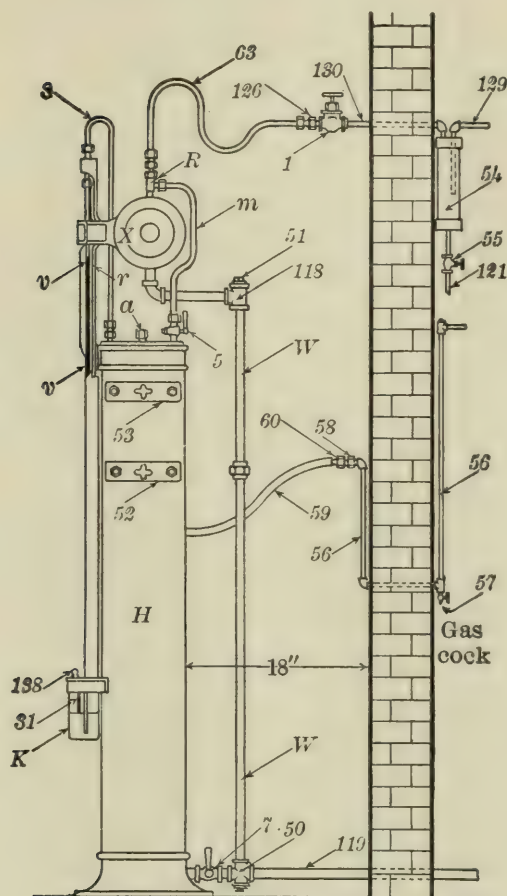


FIGURE 11.—Diagram showing how Uehling CO₂ machine should be set up.

ing water can be seen, so as to make sure that water is flowing through the condenser.

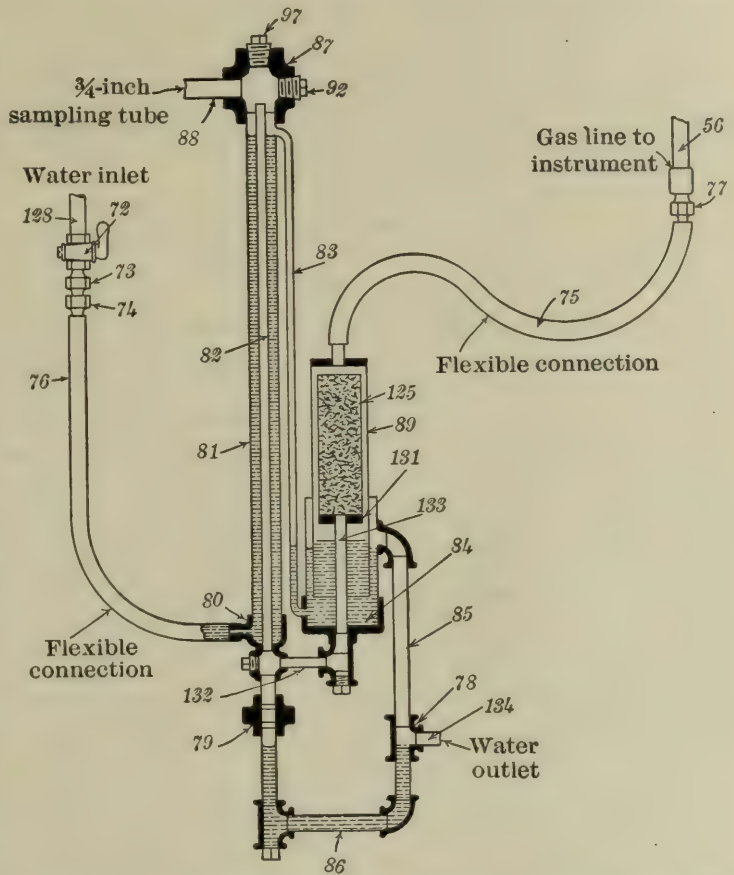
HOW CONDENSING FILTER FUNCTIONS.

Figure 12 clearly shows the function of the condensing filter. The water enters through the flexible-rubber connection 76, passes through 81, at the top of which it overflows through pipe 83. The water then fills the seal 84, whence it overflows into the bottom seal 86, leaving finally through pipe 134. The gas passes through 88 to 82 to 132 to 133, thence through the filter 125, from which it leaves through

the flexible connection 75 and arrives at the instrument by means of the $\frac{1}{4}$ -inch gas pipe 56. The flexible gas connection 75 makes it possible to lift the bell 89 out of the water seal 84. The cylindrical filter 125 can then easily be removed and replaced. Each condensing filter is supplied with two cylindrical filters 125, one of which is kept in readiness and filled with fresh waste loosely packed to take the place of the second as soon as it becomes fouled.

PRELIMINARY PIPING.

The $\frac{1}{4}$ -inch gas pipe 56 for the gas from the condensing filter (fig. 12) should be brought to the instrument as shown in figure 11. The bend in the line is to catch any vapor in the gas that might condense during the operation of the instrument. This condensation can be let out through the gas cock 57. If there is more than one CO₂ unit a separate gas line, 56, must be put up for each unit. The flexible gas connection 59 is furnished with each unit and is supplied with a $\frac{1}{4}$ -inch nipple, 58, to fit the $\frac{1}{4}$ -inch gas line from the boiler. The other end of the connection 59 is attached to gas inlet 32 (fig. 10).

FIGURE 12.—Condensing filter and connections, Uehling CO₂ machine.

Dry steam must be brought to the place where the instrument is to be placed. To insure dry steam a separator, 54 (fig. 11), can be made, or a simple drop bleeder pipe can be used. The separator is made of a 3-inch iron pipe about 3 feet long, with a cap on each end; a $\frac{1}{4}$ -inch steam supply pipe, 129 (fig. 11), should extend about halfway down the length of the separator; the outlet should be a $\frac{1}{4}$ -inch pipe, 130, fitted with a $\frac{1}{4}$ -inch valve, 1. It should be drained with a $\frac{1}{4}$ -inch iron pipe at the bottom, and supplied with a valve, 55. This drain pipe should be led to a point where the

outlet is visible, so that a slight vapor can be made to flow continually from the pipe by adjusting the valve 55; the continuous escape of a small volume of vapor from pipe 121 will insure dry steam. If the simple bleeder pipe is used, the line 129 is arranged to drop vertically a few feet just before reaching valve 1, where a tee is inserted, into the outlet of which is fitted pipe 130. The run is carried down another foot and a bleeder valve is placed. This, like valve 55, should be left partly open.

Before connecting the instrument, blow out the steam line to clear it of foreign material.

Provision also must be made to take care of the drain pipe 119. If the recorder is close to the filter, this drain pipe should not be connected to the filter drain, as the steam might back up into the filter, raising its water level, flooding the filter waste, and cutting off the gas supply to the instrument.

SETTING UP CO₂ RECORDING GAGE.

Each recording gage as shipped is ready to be screwed to the wall. The recorder must be so fastened to the wall or gage board that mercury vessel 43 (fig. 10) will be absolutely plumb. After the recorder is in place, remove cap 47 by loosening clamp 48. Remove from the inside of the mercury vessel the block of wood which is put there to hold bell 41 in place for shipment. After the block of wood has been removed, pour into the opening at the top all the mercury furnished for the gage. After the mercury has been poured in, add the contents of the small bottle, a special oil with which to cover the mercury to prevent oxidation. After the mercury and oil have been poured in, replace cap 47. See that a rubber band is around its neck before replacing the cap, so that a tight joint can be made by means of clamp 48. Do not force the screw 49.

After the cap 47 has been properly replaced, the gage will be ready for connection with the main instrument. Connection is made by means of a $\frac{3}{16}$ -inch drawn-copper tubing with flange and nut at each end. Have as few bends as possible in this tube, which will be found in the box with the recorder. One end is joined to the connection at the top of the recording gage and the other end to one of the connections on the filter F' at the steam pot (fig. 10). Filter F' is the small aperture filter with which the top of absorption chamber N is connected. All connection points will be found blanked off with nuts and disks, which must be removed and saved for possible future use.

SETTING UP AUXILIARY CO₂ INDICATOR.

The indicator G is usually screwed to the boiler front or any other place convenient for the fireman's observation to serve as a guide in firing.

After the indicator has been properly fastened, screw out plug 139 and pour into reservoir 16 the special indicator oil furnished with the instrument. This oil will be found in a can marked "Special oil for CO₂ indicator." The entire contents should be poured into the reservoir 16, and the plug 139 should then be replaced. The auxiliary indicator is connected with the instrument by means of a $\frac{3}{16}$ -inch drawn-copper tube with flange and nut at each end. This tubing will be found in the box with the main instrument. One end is connected to the top of the indicator and the other end to one of the connections on filter *F'* at the steam pot.

FILLING REGULATOR.

Before connecting the instrument with the drain pipe 119 (fig. 11) unscrew plug 51 at the top of the exhaust pipe *W* and insert it into the open end of cross 50. Open cock 7. Insert a funnel into tee 118 and pour in exactly 11 gallons of clean water. Then close cock 7, take out the plug that was inserted into cross 50, and replace it tightly into fitting 118. See that cocks 6, 5, 4, and 2 on the instrument (fig. 10) are closed and that cock *J* at the top of the filter *D* is open. The core of this cock must be in such a position that the small cross mark is horizontal and at the bottom.

INSERTING CAUSTIC CARTON.

To insert the caustic carton 14 (fig. 10), loosen wing nuts 23 at the top and bottom of *N*, remove *N* from between 27 and 18 and punch 15 to 20 large holes into each end of the carton with a lead pencil. Put the round rubber ring 10 around the bottom end of the carton. Push the carton into *N* and replace *N*, making sure that the carton sets down against cap 18, as shown in figure 10. A round rubber ring between 27 and 28 will be found in place, where it must remain. The rubber ring at the top is not placed around the carton and only prevents leakage between 27 and 28. Rubber ring 10 makes a tight joint between 17 and 18, and, as the wing nuts are tightened, makes a tight joint about the carton, preventing the passage of gas around it.

Fill vessel *K* with clean water up to index rod 31. Connect the aspirator *R* with valve 1 by means of copper tube 63 (fig. 11). This tube is 2 feet 6 inches long and will be found tied to the exhaust pipe. It can be bent to fit. It has at one end a nipple, 126, that will fit the $\frac{1}{4}$ -inch valve 1.

THE CO₂ THERMOSCOPE. INSTRUMENT 6.

DESCRIPTION.

The CO₂ thermoscope consists of the following main parts: (1) A cylinder fitted with a plunger for drawing from the flue the gas mixture to be analyzed; (2) a small cartridge-shaped receptacle con-

taining granular caustic alkali, in which the heat reaction occurs; and (3) a special thermometer with its bulb constructed to surround or jacket the cartridge so that the heat of reaction can be imparted to the mercury, the amount of its expansion (read as the percentage of CO_2) being observed on a movable scale.

Figure 13 clearly shows the parts and their relations. At *a* is shown a cylinder fitted with a piston and cup leathers and provided with a three-way cock *i* at its end.

The thermometer *b* is mounted on the cylinder *a*, and the whole is inclosed by the cylindrical jacket *c*, which is slotted at *d* to show the thermometer stem. A movable scale *e*, calibrated to show percentages of CO_2 by volume, is arranged to slide in the slot.

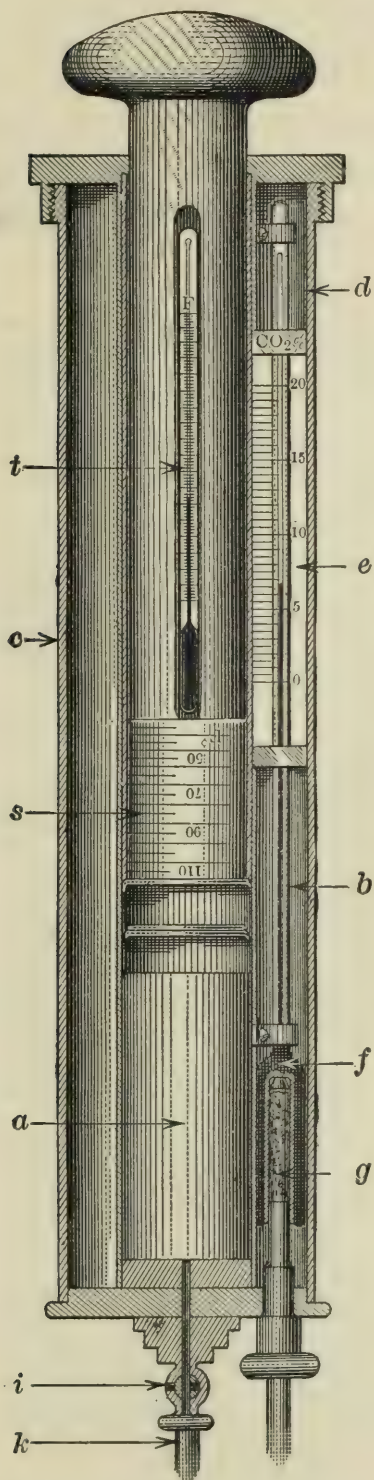
The thermometer bulb *f* is blown so as to form a cylindrical jacket, in which is inserted the cartridge *g*, containing caustic alkali in the form of a dry granular powder. When the instrument is to be used, the cartridge is pricked at each end. In order that the gas under examination may flow through, a needle mounted in a cavity in the end of the piston rod is used to prick the carton. At *k* is a rubber-tube connector for delivering the gas from the cylinder *a* to the interior of the cartridge.

In order to correct the volume of the gas drawn into the cylinder for varying room temperatures, the length of the piston stroke when taking the sample is regulated by a temperature scale *s* on the piston rod, the room temperature being read for convenience on the thermometer *t*, which is placed in a cavity of the piston rod, or by any thermometer in the room.

MAKING AN ANALYSIS.

FIGURE 13.—The CO_2 thermoscope.

Directions for making an analysis are as follows: Place the rubber connection *k* over the nipple at valve *i*. Its end for the brass cartridge will fit nicely into any ordinary rubber hose that will carry the sample from the sampling tube.



In handling the instrument do not allow the hands to grasp it at the bottom end where the thermometer bulb is located, as the heat of the hand will move the mercury, and time will be lost in waiting for it to come back to room temperature.

Prick a cartridge at both ends, using the needle in the end of the piston rod, and lay aside for the moment. Draw the gas sample. By operating the three-way cock at each stroke the instrument works as a pump. Thus after a few strokes the pipe leading to the sampler is cleared and an undiluted gas sample is obtained. Break the connection between *k* and the sampling pipe and place the cartridge snugly on the end of *k*. Insert the cartridge into the thermometer bulb *f*. It should fit and stay up tight to the rim on the rubber.

A wait of $1\frac{1}{2}$ minutes to 3 minutes is necessary after the cartridge has been placed in the thermometer, as the warmth of the hand in making it ready will cause a rise of the thermometer equivalent to about $1\frac{1}{2}$ per cent CO_2 . If this care is not taken, the analysis will show too high a CO_2 content. Compress the pump to the proper temperature mark on the stem, that mark being read on the room-temperature thermometer. Pull the connector off the valve *i* for the instant and open *i* to the atmosphere to create atmospheric pressure in the pump. There should be a slight puff as the gas in the pump is under a slight compression above atmospheric. Replace *k* and adjust *i* so that the gas will flow from the pump through the cartridge.

Set the sliding scale *e* with the zero at the end of the mercury column. Be sure that all rapid movement of the column has ceased, or that it is at a point representing room temperature for the column, and hence will make no changes due to that source. Force the gas through the cartridge. The stroke should be smooth and easy, requiring about five seconds. A few seconds more or less than five will result in a CO_2 indication 0.5 to 1 per cent low. Six seconds is much preferred to four seconds. If the stroke seems rather hard, a passage is probably stopped up partly, and good results can not be had. The heat due to the chemical action will now heat up bulb *f*, and the maximum point to which the column rises will register the CO_2 content.

The greatest source of error is in trying to make too many analyses per hour. Six records per hour is a maximum number unless artificial cooling of the indicating thermometer bulb is used. If, after one analysis has been taken, another is attempted before the mercury, although seemingly stationary, has returned to its original position of zero on the scale, a low result of several per cent will be caused. If the instructions are followed carefully, an error of 0.3 CO_2 is the maximum that may appear

DR. A. SCHMID'S POCKET CO₂ INDICATOR. INSTRUMENT 7.

The Dr. A. Schmid's pocket CO₂ indicator is shown in figure 14. Cock *a* is removed and a solution of KOH (250 grams of potassium hydrate dissolved in 1 liter of water) is poured into the lower bulb by means of the small funnel furnished. One filling is enough for about 200 determinations of CO₂. When the instrument is not in use, a rubber stopper is inserted in place of glass cock *a*.

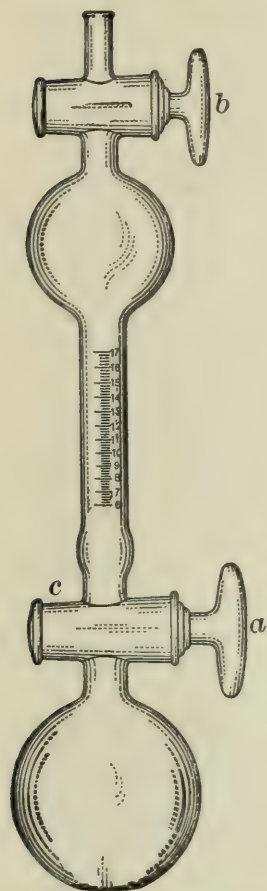


FIG. 14.—Dr. A. Schmid's pocket CO₂ indicator.

MAKING A DETERMINATION.

To make a determination, the glass cocks *a* and *b* are put into place, *a* being the cock with one blue tip. The rubber pump furnished is placed on the glass nipple above cock *b*. The other end of the pump is placed on the gas line from which sample is to be taken. Cock *a* is so placed as to throw the small hole *c* open. Gas is then pumped in. The lower cock is closed, the rubber pulled from the top, and the upper cock closed. This arrangement insures atmospheric pressure in the bulb at the start.

The lower cock *a* is now opened with the blue tip downward. The instrument is held inclined downward and shaken until the upper bulb is about half full. It is then stood upon its base and the gas in the lower bulb comes up, a bubble at a time. When the KOH has found its level, the lower cock is closed. The instrument is now held upside down and lowered vertically into water. The submerged cock is opened and the ingoing water is leveled with that outside. In leveling

the water in the submerged bulb with that outside an error as high as 0.3 per cent can be made.

To get accurate results, use a glass beaker large enough for convenient manipulation of the submerged cock, and take the leveling sight from below the water level. Place a light back of the beaker if necessary. The cock *b* is closed and the instrument stood on its base. The small stem above cock *b* should be completely filled with water, as the water is to replace the air forced into the indicating tube from the stem when the instrument was lowered into the water. The upper cock is now opened just long enough to allow the water to run down into the tube. After some 30 seconds, the exact number depending upon how dirty and sticky the side walls are, the percentage of CO₂ is read. The instrument is turned upside down, and cock *b* opened, and the instrument is ready for another sample.

MISCELLANEOUS INSTRUCTIONS.

As the walls of the vessel have a coating of KOH on their sides, the incoming water is made highly alkaline; after the water has been poured out the walls are still alkaline. The next sample is liable to have a part of its CO_2 content removed by the caustic solution on the walls of the instrument before it is closed from the atmosphere. Therefore the instrument should be purged by pumping gas through it. The purging will require some 20 or more strokes of the pump, the number depending on the gas and the solution. If this precaution is not taken, the result will be a low CO_2 indication. As the second sample is pumped in, it puffs out little drops of water from the small hole in the lower cock. The water thus ejected is highly alkaline and should be caught with some waste or it will run down on the lower bulb and get on the operator's hands when the instrument is shaken.

Much care must be taken to insure that the glass cocks move easily and without any air leakage. The lower cock is apt to bind because of the action of the caustic. Keep plenty of vaseline or its equivalent on the cocks. As the caustic during manipulation is apt to get a little low, water can be let down to fill the lower bulb.

In order to determine the maximum error due to temperature changes incident to the manipulation of the indicator, proceed as follows: Make one determination of the CO_2 content of a sample of gas in the ordinary manner, being careful to keep the hands off of the upper or gas bulb of the instrument as much as possible. After taking the reading hold the hands on the gas bulb for some time; then relevel quickly in the water and take a second observation of the CO_2 indication. The difference between the two observations represents the maximum error due to temperature changes.

With careful manipulation an analysis will take about three minutes. Determinations made in this way will be accurate within ± 0.2 per cent CO_2 .

GENERAL CONCLUSIONS FROM TESTS.

The following brief summary of conclusions from tests of the CO_2 recorders herein described indicates the scope and character of the tests. The conclusions are amplified in subsequent pages.

1. Evidence of a change in the composition of a gas being tested is shown by each of the recording instruments soon after the change takes place, the maximum time for such evidence to show being 8 minutes. The correct registration of the percentage of CO_2 (permissible error 0.5 per cent) requires a longer time, which varies considerably with the type. Such changes indicate the lag of the instrument, defined as the time interval elapsing after gas enters the instrument and until the CO_2 content is correctly registered on the chart.

The item of lag may or may not be important, depending on the purpose for which the instrument is to be used. The lag of the system will be the lag due to the instrument plus that due to the piping to the boiler, the latter depending on the length and diameter of pipe used.

2. When properly set up, and so long as the instrument remains in adjustment, the error of the record, when the composition of the gas is not changing, varies between 0.1 and 0.5 per cent CO_2 , according to the type of instrument.

The introduction into the system of gas-storage capacity, such as a large filter, will result in a reduction of the fluctuations of the record curve, although the average will be the same. It should be pointed out that the cross-sectional area of the gas stream in the filter is also a factor affecting the form of the record curve, for if the area is large diffusion will take place, and a longer time will be required to purge the filter.

3. Changes in the temperature of the surrounding air, in the boiler draft, and in the speed of the instrument caused an appreciable error in the CO_2 record for some types of recorders.

4. The life of a single charge of the alkaline reagent used in all recording instruments (except No. 4) for removing the CO_2 content from the flue gas varied from 500 to 5,100 per cent hours, according to the type of instrument. Per cent hour is defined as the product of the CO_2 content and the number of hours the gas was being analyzed. For example, 1,000 per cent hours would mean an indication of 10 per cent CO_2 for 100 hours or a 5 per cent gas for 200 hours.

5. The ordinary daily attention necessary, such as winding the clock, changing the chart, and inking the pen, will require 5 to 15 minutes of the fireman's time once a day. Adjustments, changing of reagents, and any special care should be left to the engineer or some one else who thoroughly understands the instrument. The amount of such attention that will be necessary will vary from time to time and with the type of instrument. The time required to change a reagent differed considerably for the several recording instruments, ranging from 5 to 45 minutes.

6. The expense of maintenance (not taking into account the time required for adjustments or other special attention) was, for the several months during which the instruments were being tested, practically confined to the cost of the reagent.

7. The observations of CO_2 content made with the proper manipulation of the indicating (not recording) instruments were correct within 0.3 per cent CO_2 . The care and skill required for such operation depended on the type of indicator.

8. With each instrument it is necessary for some one in charge to become entirely familiar with the principle and the manipulation of the instrument. The things that may happen to the instrument to interfere with its proper working are usually easily remedied, but are not always evident to casual inspection, and therefore a considerable

degree of patience and understanding is required to insure continued operation. The character of the instrument, moreover, is such that it should be placed in the charge of some one who is qualified to handle instruments or mechanisms of a delicate nature. This service is not beyond what can reasonably be expected from an engineer employed in plants likely to profit by an investment in such an instrument. It is believed that much of the trouble with these instruments arises from the fact that the persons who are responsible for their proper operation

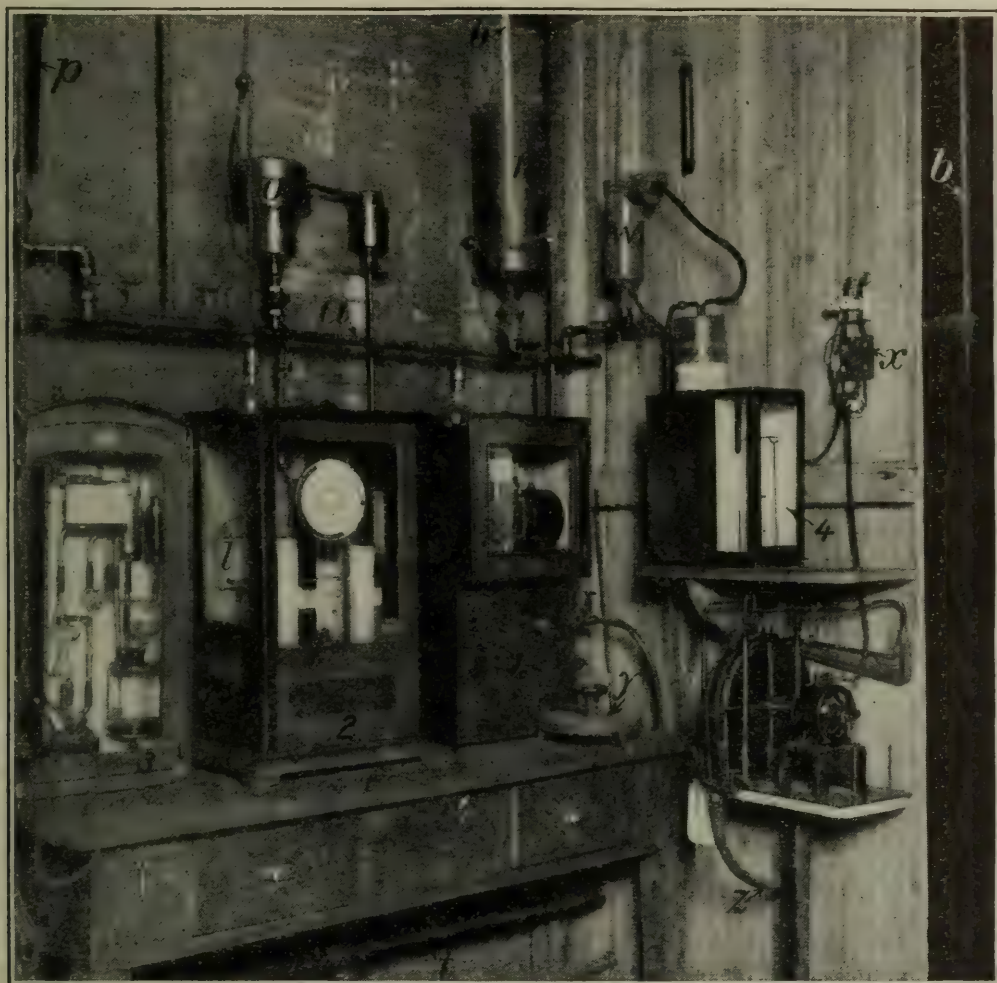


FIGURE 15.—CO₂ recorders 3, 2, 1, and 4 as set up for tests.

are not thoroughly and properly instructed. This oversight is probably due in part to the fact that the seller does not feel justified in taking the time to follow up the sale of an instrument by thoroughly instructing the employee of the buyer who is to operate the instrument. Such action is believed to be necessary to the successful installation of these devices.

ARRANGEMENT OF APPARATUS IN THE TESTS.

The various instruments were, in all essential details, set up according to the makers' instructions. In order to obtain the desired data the apparatus was arranged as shown in figures 15, 16, and 17.

In figures 15 and 16, *a* represents the main gas line of $\frac{3}{4}$ -inch piping connecting the instruments to the sampling tubes of several power boilers any one of which could be thrown on the line. The gas line was about 45 feet in length. The line *b* (fig. 15) was an auxiliary

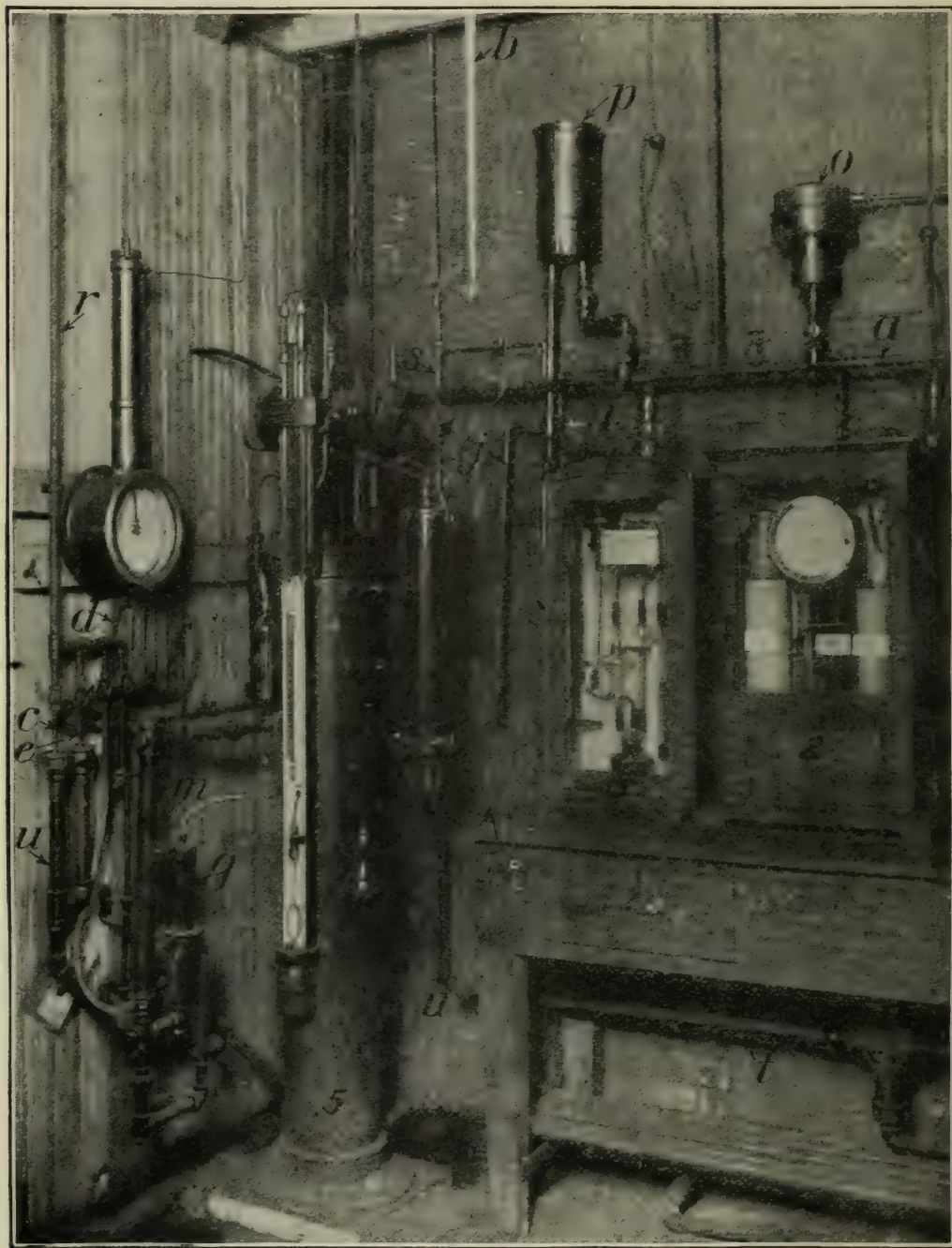


FIGURE 16.—CO₂ recorders 5, 3, and 2 as set up for tests.

line from the gas tank or gasometer *g* (fig. 17), which could be thrown on and off the main line by the manipulation of the proper valves. Gasometer tank *g* (fig. 17) was a water-sealed bell; the pressure within the bell, shown by gage *k* (fig. 17), could be controlled by the balancing weights *h*. This tank could therefore supply

a gas of uniform CO_2 content at any pressure for standardizing purposes.

At the instrument end of line *a* was a drop bleeder pipe to catch the moisture, which was removed by taking off a cap at the end of the drop. Here also compressed air could be connected to clear out the whole line. Aspirator *c* (fig. 16) at the end of the line kept a constant flow of gas through the piping, in addition to that which the instruments were causing. The draft on the line was shown by gage *d* (fig. 16).

Filters *w*, *n*, *o*, and *p* (fig. 15) were piped from the top of the gas line, and *mq* (fig. 16), the condenser filter for machine 5, was connected at the end as shown. From these different points the instruments, with the exception of instrument 3, were connected according to the maker's directions. The makers connect instrument 3 in such a manner as to cause a continuous flow of gas along pipe *j* (fig. 6). In order to simplify the piping layout there was substituted for this a flow along pipe *j* caused by aspirator *e*, the draft of which was shown by gage *f*.

Water was supplied from a tank placed on top of the recorder booth and equipped with a float valve so as to keep a constant head of water at the instruments. The water for aspirators *c* and *e* and for instrument 5 was supplied by the pipe *r*. Line *t* took the drainage from instruments 1, 2, and 3, as well as the water drip from the steam line *s*. Line *u* carried the drainage of the aspirators *c* and *e* and of the condenser filter *q*, and served as the drain for the steam aspirator of machine 5. The outlet for machine 4 was at *z* (fig. 15). The electric current was brought in at switch *x* (fig. 15) for machine 4 and passed through the controlling resistance *y* before reaching the motor.

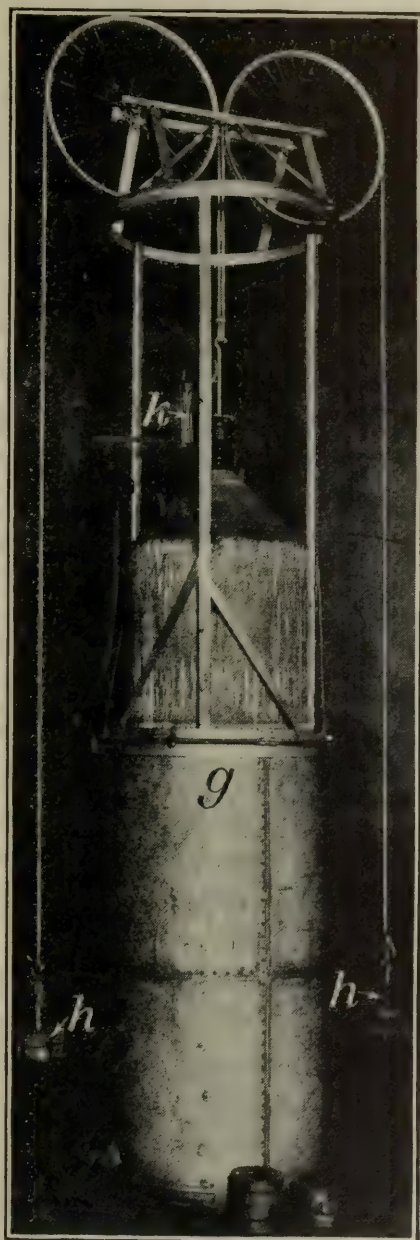


FIGURE 17.—Gasometer tank.

OUTLINE OF TESTS.

The tests of the instruments may be divided into two classes, as follows:

First, special or laboratory tests, which include the determination of the lag and of the effect of changes in boiler draft and room temperature, also any tests suggested by the mechanism of the instrument itself and peculiar to it.

Second, endurance tests, in which the instruments were run day after day on the gas from a power boiler, as would occur in practice.

In order to ascertain the lag of each instrument, it was run at a definite speed under regular working conditions, with a constant draft and temperature, and drawing a gas of unvarying CO_2 content through its filter and gas line. The gas was drawn from the gasometer, and its exact CO_2 content was determined by a number of analyses in the chemical laboratories. After the CO_2 content had been registered correctly as shown by several determinations, a gas of different CO_2 content was admitted to the line and the time that was required for the instrument to correctly register the second gas was noted. In some instances, the gas was also admitted directly to the instrument proper thus eliminating the lag due to the filter and gas line.

To determine the effect of a change in boiler draft the devices were supplied with gas of uniform CO_2 content, and the draft pressure was varied by means of the balance weights on the gasometer, the temperature and speed being kept uniform.

To determine the effect of a change in the surrounding temperature, the CO_2 content, draft, and speed were kept uniform, and the surrounding temperature was suddenly lowered and held at the lower temperature.

The endurance tests consisted in operating the machines under service conditions and noting all the care and attention necessary to keep them recording correctly. These tests covered a period of several months. Every eighth day the devices were standardized by allowing them to run on gas of known CO_2 content taken from the gasometer to ascertain whether they were still recording correctly. By this means the required frequency of renewal of the reagents was also determined.

The tests of the indicating instruments consisted of an extended series of analyses of gases of known CO_2 content. The tests indicated the proper manipulation, the skill and care required for such manipulation, and the errors likely to occur in the handling of the instruments.

TABULATED RESULTS OF SPECIAL TESTS.

The tabulated results of the special tests follow. The graphic records mentioned in the tabulation are shown in figures 18 to 22. Graphic records obtained from the recorders under normal operating conditions are shown in Plate I and figures 23 to 25.

*Tabulated results of special tests of CO₂ recorders.*TESTS FOR LAG.^a

Instrument No.	Change of gas.	Speed of recorder.	Time taken to make completed record.	Time taken to make record within 0.5 per cent.	For graphic record, see —
	<i>Percentage of CO₂.</i>	<i>Records per hour.</i>	<i>Minutes.</i>	<i>Minutes.</i>	
1.....	6.0 to 0.0	17	41	30	No. 1, fig. 18.
	0.0 to 6.5	17	39	35	No. 2, fig. 18.
	6.5 to 4.5	19	35	20	No. 3, fig. 18.
2.....	9.0 to .0	16	33	22½	No. 1, fig. 19.
	0.0 to 6.5	16	34	23	No. 2, fig. 19.
	7.0 to 2.5	16	34	23	No. 3, fig. 19.
	^b 8.5 to .0	16	13	9½	No. 4, fig. 19.
3.....	^b 6.5 to .0	48	9	5	No. 2, fig. 20.
	^b 0.0 to 6.5	48	16	14	No. 1, fig. 20. No. 3, fig. 20. ^c
		<i>Revolutions per minute.^d</i>			
4.....	0.0 to 10.7	1,660	8	6	Nos. 14-1, fig. 21.
	0.0 to 7.5	1,660	5	.....	Nos. 11-12, fig. 21.
	7.5 to .0	1,660	34	30	Nos. 12-13, fig. 21.
5.....	7.0 to .0	.....	70	^e 40	No. 1, fig. 22.
	0.0 to 6.0	.....	17	8	No. 2, fig. 22.
	6.8 to 5.2	.....	6	.....	No. 3, fig. 22. No. 4, fig. 22. ^c

EFFECTS OF CHANGES OF OPERATING CONDITIONS.^f

Instrument No.	Temperature.			Draft.			Speed.		
	Temperature change.	Change in CO ₂ indication.	For graphic record, see —	Water-draft change.	Change in CO ₂ indication.	For graphic record, see —	Speed change.	Change in CO ₂ indication.	For graphic record, see —
	^g ° F.	^h Per ct.		ⁱ Inches.	^j Per ct.		<i>Records per hour.</i>	^k Per ct.	
1.....	98 to 75	None.	.....	0.0 to 1½	None.	.....	18 to 4	None.	.....
2.....	98 to 75	+1.0	Nos. 9 and 10, fig. 19.	½ to 0.0	-0.5	No. 13, fig. 19.	16 to 8	+0.5 to +1.3	Nos. 11 and 12, fig. 19.
				0.0 to 1½	+1.5	Nos. 5 and 6, fig. 19.			
3.....	98 to 75	-1.0	Nos. 4 and 6, fig. 20.	0.0 to 1½	None.	.....	48 to 12	0.0 to -0.5	Nos. 4 and 5, fig. 20.
							<i>Revolutions per minute.</i>		
4.....	81 to 89 ^g	.....	No. 10, fig. 21.	¾ to ½	-0.7	Nos. 1 and 2, fig. 21.	1,660 to 2,000	+3.3	Nos. 4 and 6, fig. 21.
	79 to 84 ^h	+1.4	.....	¾ to 1¾	+1.4	Nos. 1 to 3, fig. 21.	1,660 to 1,920	+2.8	Nos. 4 and 5, fig. 21.
5.....	98 to 75	+0.2	No. 5, fig. 22.	0.0 to 1½	None.	.....	.....	.....	.....

^a With regard to statements as to lag and limits of accuracy, it should be borne in mind that the fundamental standard used as a basis of comparison was the analysis as made in the chemical laboratory, which in itself may have been in error 0.2 per cent.

^b Determined by admitting the gas directly to the instrument proper (see p. 41).

^c Shows general form of lag curve when gas is drawn through filter.

^d Refers to speed of the two centrifugal fans.

^e The time taken to drop the last per cent when approaching zero varied greatly, whereas to drop to about 1 per cent required only about 10 minutes.

^f Charts obtained under normal operating conditions are shown in figures 23 to 25 and Plate I.

^g At fan.

^h At filter.

ⁱ Then dropped to -0.3 per cent.

SUMMARY OF RESULTS AND CONCLUSIONS FOR EACH INSTRUMENT.

INSTRUMENT 1.

Instrument 1 had a lag ^a averaging 28 minutes for an indication to the nearest 0.5 per cent, whereas, on the average, 38 minutes was required for the instrument to complete its record of the change.

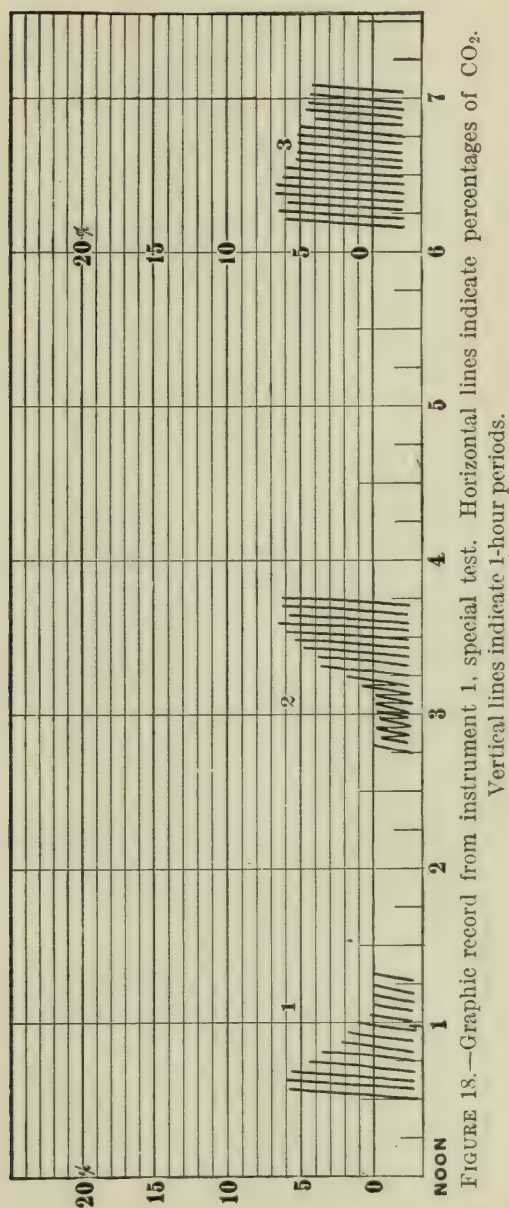


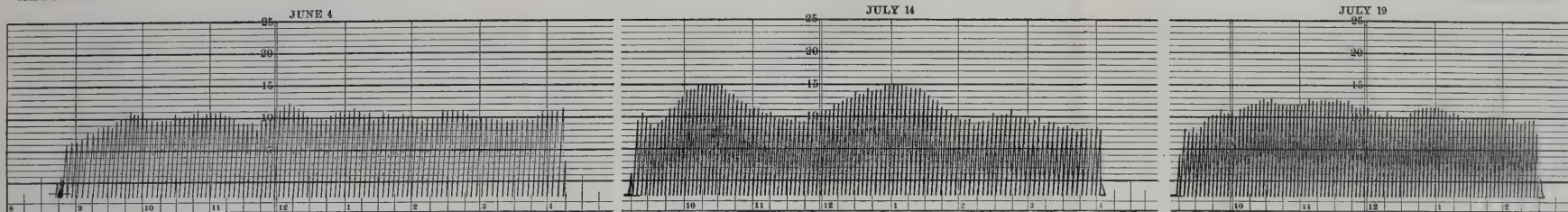
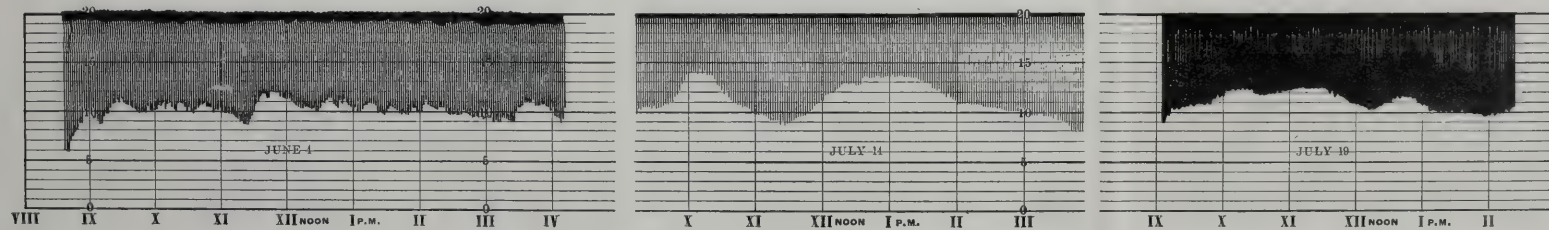
FIGURE 18.—Graphic record from instrument 1, special test. Horizontal lines indicate percentages of CO₂. Vertical lines indicate 1-hour periods.

Evidence of a change in composition began to show at about the second analysis, or about 5 minutes after the change occurred. When operating at 23 records per hour, the instrument drew a sample of 1.73 cubic feet of gas per hour. It could be regulated to record a maximum of about 30 analyses per hour. As long as the instrument was kept in proper adjustment the maximum error for any given analysis, when the instrument was operating on gas whose composition was not changing, was ± 0.5 per cent CO₂. Its accuracy was not affected by change of room temperature, boiler draft, or number of records per hour. The absorption chamber contains as the reagent slaked lime, which is distributed through loosely packed excelsior in a jar. Proper packing of a jar required from 30 to 45 minutes. The time that one of these charges will last can not be closely estimated owing to the difficulty of packing two jars exactly alike. This time varied from 555 to 1,194 per cent hours,^b averaging 740 per cent

hours. In order to ascertain whether the reagent was still active it would be necessary to make a check analysis with some other apparatus. This can not be conveniently done unless there is available a gasometer or other vessel to hold a quantity of gas of known composition. It is therefore advisable to change the reagent about as often as recommended. The ordinary daily attention required about

^a Defined on p. 37.

^b Defined on p. 38.

A. GRAPHIC RECORD FROM BIMETER CO₂ RECORDER, NORMAL OPERATION.B. GRAPHIC RECORD FROM "SARCO" AUTOMATIC COMBUSTION CO₂ RECORDER.

five minutes of a fireman's time. The pen gave considerable trouble and wore out in less than a year. The water piping in this instrument is liable to clog frequently if dirty water is used.

INSTRUMENT 2.

Instrument 2 had a lag averaging 23 minutes for an indication to the nearest 0.5 per cent, and on the average 34 minutes was required for the instrument to complete its record of the change. Evidence of a change in composition began to show at about the second

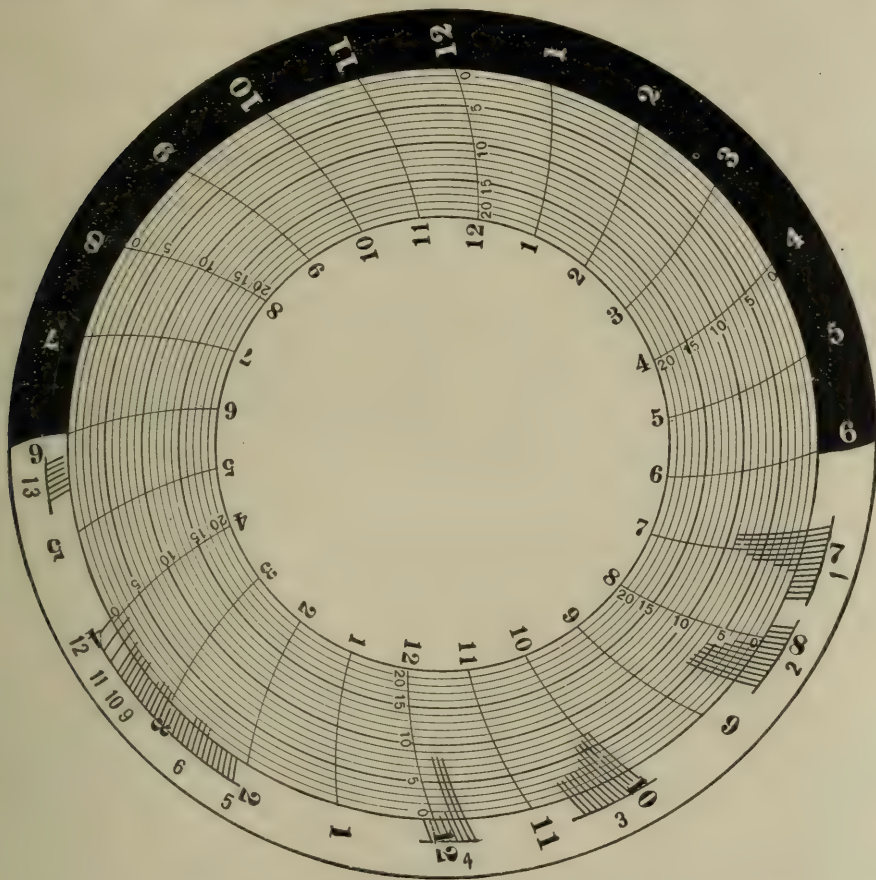


FIGURE 19.—Graphic record from instrument 2, special test.

analysis. When operating at the rate of 16 to 17 records per hour the instrument drew a sample of 0.6 cubic foot of gas per hour. It could be regulated to record a maximum of 16 or 17 records per hour. As long as the instrument was kept in proper adjustment the error for any given analysis when the instrument was operating on gas whose composition was not changing was ± 0.1 to ± 0.2 per cent CO_2 , which is about as close as the chart can be read. The accuracy of the device was affected by change of room temperature, draft, and the number of records per hour as shown in the table on page 43. The greatest source of error was the persistent leaking of gas through the joint between the caustic potash (KOH) tank and its cover. The leak was stopped repeatedly by painting the joint with asphaltum paint,

but the caustic would open a hole again after a time. The reagent—a solution of caustic potash (KOH) in water with a specific gravity of 1.27—lasted about 5,100 per cent hours. To change a solution

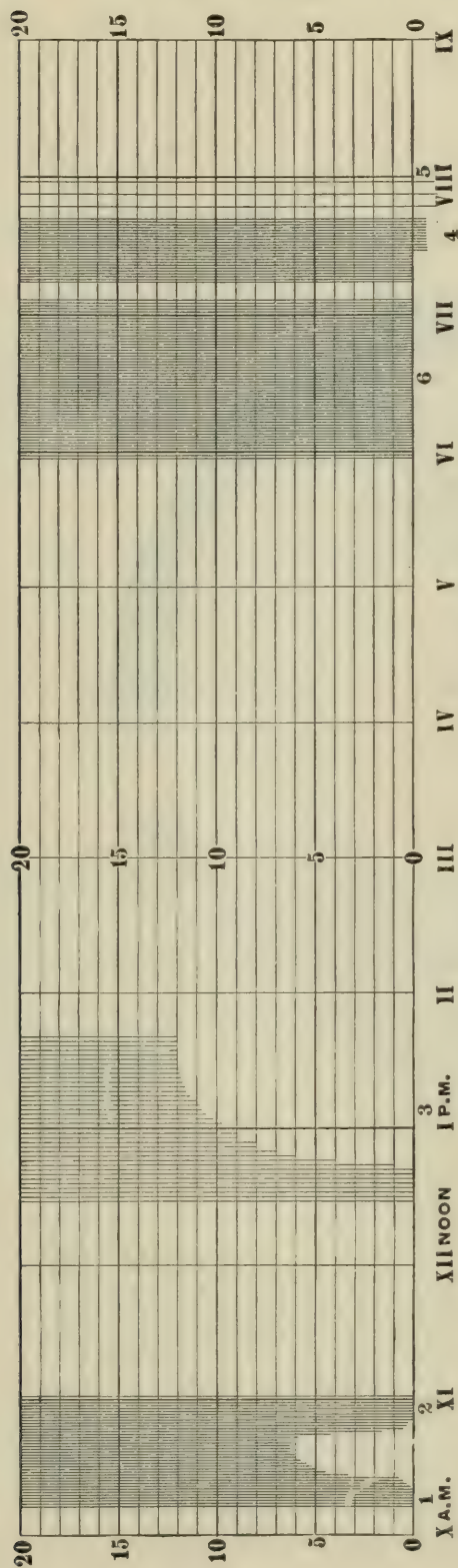


FIGURE 20.—Graphic record from instrument 3, special test.

required about 15 minutes. The time that one of these changes will last can be fairly well estimated. In order to ascertain exactly when a charge has been entirely used it would be necessary to make a check analysis with some other apparatus. This can not be conveniently done unless there is available a gasometer or other vessel to hold a quantity of gas of known composition. It is therefore advisable to change the reagent about as often as recommended. The ordinary daily attention required about 8 to 10 minutes of a fireman's time. Considerably difficulty was experienced in regulating the continuous water supply to maintain the proper water levels, and the use of this part of the apparatus was abandoned.

INSTRUMENT 3.

As instrument 3 has no device with which to draw the gas sample from the sampling tube through the gas line and filter, its lag would depend on the outside means used in drawing in the sample. The part of the lag due to the instrument proper and exclusive of that due to the gas line and filter averaged 9 minutes for an indication to the nearest 0.5 per cent and 12 minutes for a completed record of the change. Obviously these figures can not be compared with those for the other instruments, which include

the filter and gas line. Evidence of change in composition began to show at about the second analysis after the change. The instrument

could be regulated to record a maximum of about 50 analyses per hour, although 30 is suggested for regular operation. As long as the instrument was kept in proper adjustment the maximum error for any given analysis when the instrument was testing gas whose composition was not changing was ± 0.4 per cent CO_2 . Its accuracy was not affected by change of boiler draft, but was affected by change of room temperature and the number of records per hour. The reagent—a solution of caustic potash in water, specific gravity 1.27—lasted 2,260 to 2,490 per cent hours, averaging 2,375 per cent hours. To change a solution required about 5 minutes. The time that one of these charges will last can be fairly well estimated. In order to ascertain exactly when a charge has been entirely used, it would be

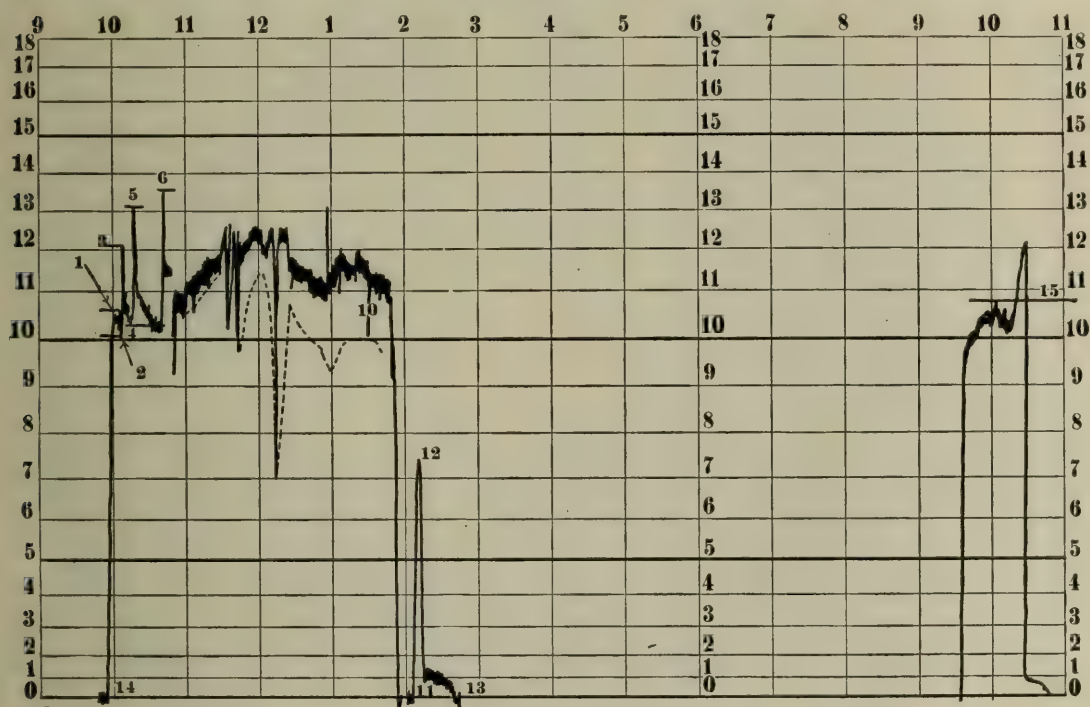


FIGURE 21.—Graphic record from instrument 4, special test. Dotted line represents the record of another recorder plotted here for comparison.

necessary to make a check analysis with some other apparatus, as previously explained. Instead of attempting this it is advisable to change the reagent about as often as recommended. The ordinary daily attention required about 8 to 10 minutes of a fireman's time. Considerable trouble was experienced with the nib type of pen on account of clogging. The rubber connections lasted 12 months or more, with the exception of that under the caustic potash tank, which lasted about 2 months. These parts are readily replaced.

INSTRUMENT 4.

When a gas of higher CO_2 content than had been running to the sampling tube was admitted, instrument 4 had a lag of about 6 minutes for an indication to the nearest 0.5 per cent and of about 8 min-

utes for a completed record of the change. When a gas of lower CO_2 content was admitted, the lag for an analysis to the nearest 1 per cent was about 5 minutes, and to the nearest 0.5 per cent the lag was about 30 minutes; about 34 minutes was required for a completed record. Evidence of a change in composition began to show practically at once. Under normal working conditions it drew a sample of 2.4 cubic feet of gas per hour. As long as the instrument was kept in proper adjustment the maximum error when the instrument was

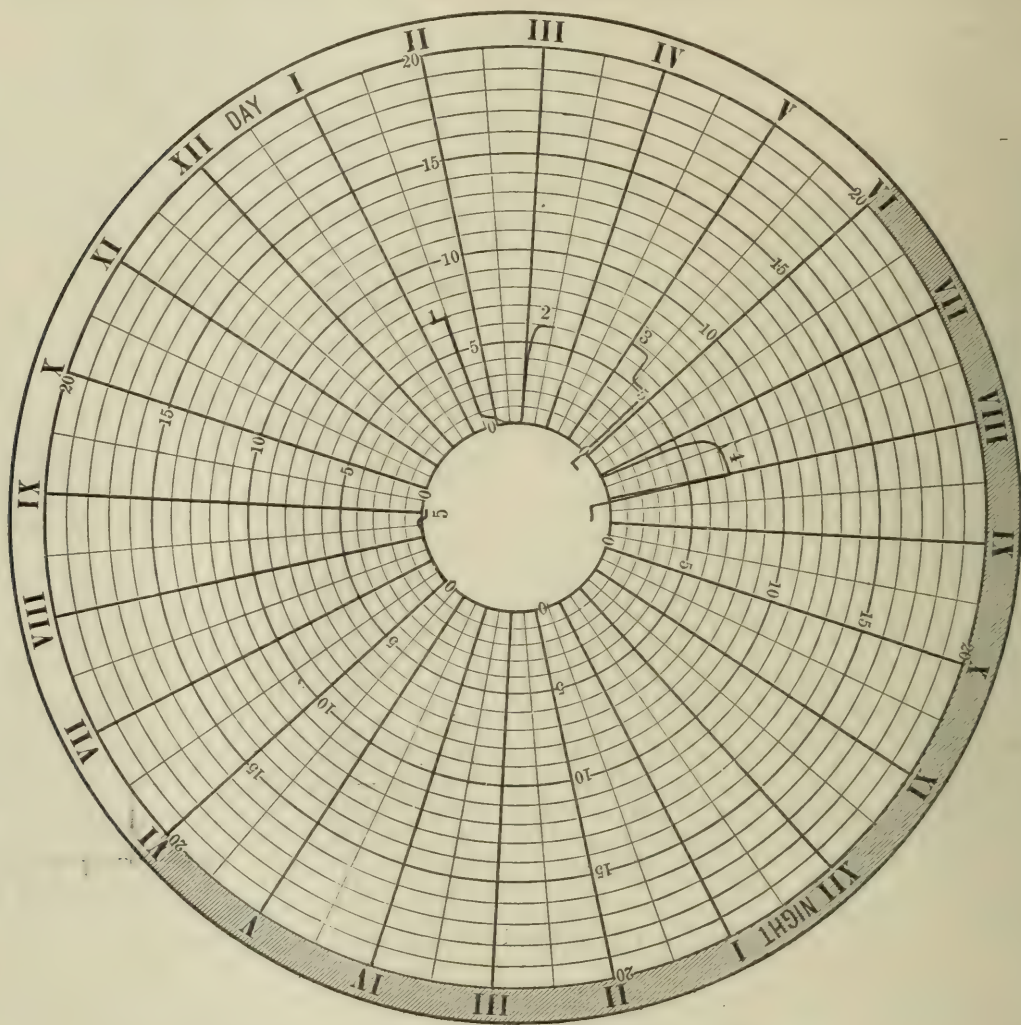


FIGURE 22.—Graphic record from instrument 5, special test.

sampling gas whose composition was not changing was about ± 0.2 per cent CO_2 , which was about as close as the chart could be read. Accuracy is affected by changes of room temperature, boiler draft, and speed of fan. The instrument makes use of no reagent and hence requires no attention in this respect.

INSTRUMENT 5.

The lag of this machine was about 5 to 8 minutes for an indication to the nearest 0.5 per cent, except when a gas containing no CO_2 was admitted to the sampling tube. The time required for a complete

record of the change varied as shown in the table on page 43. Evidence of a change in composition began to show practically at once. The instrument gave a continuous indication and record of CO_2 content. As long as the instrument was kept in proper adjustment the maximum error when operating on gas whose composition was not changing was about ± 0.1 per cent CO_2 , which was about as close as the indicator could be read. Its accuracy was affected slightly by change of room temperature but not by change of boiler draft. The reagent is sodium hydroxide (NaOH) packed in pasteboard cartons that fit in

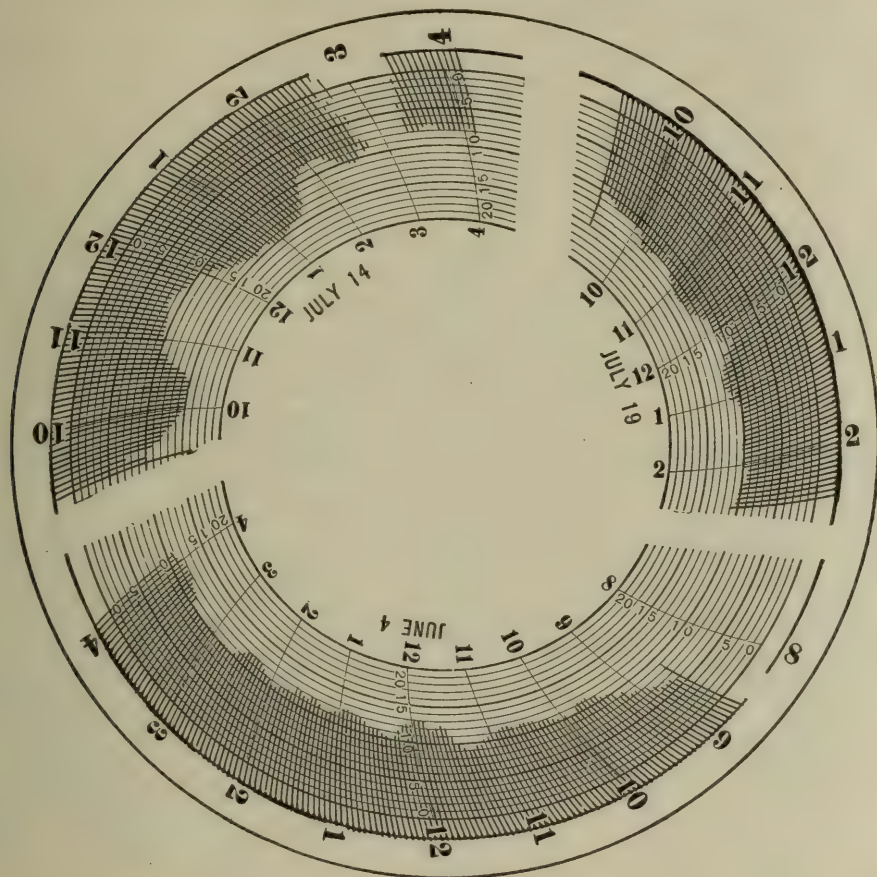


FIGURE 23.—Graphic record from instrument 2, normal operation. The failure of the instrument to record during the 3 o'clock period on July 14 was due to the curling of the chart.

a case on the instrument. The cartons are obtained from the manufacturer packed and ready for use in the instrument. They lasted 500 to 1,185 per cent hours, averaging 870 per cent hours. For practical purposes the condition of the reagent and the time when it should be replaced are readily ascertained while the recorder is in operation by locating with the hand the position of the hottest zone on the carton case; when the hot zone is near the top the carton nears exhaustion. In order to determine exactly when a charge has been entirely used, it would be necessary to make a check analysis with some other apparatus. Inasmuch as this can not be readily done, it

is advisable to be governed by either the per cent hours or the location of the heated zone in changing cartons. The ordinary daily attention required about 8 or 10 minutes of a fireman's time.

This machine has a boiler-room indicator in addition to the chart record and to the indicator on the instrument proper. The boiler-

room indicator may be placed on the boiler front or in any convenient place in the boiler room, and need not be close to the recorder.

INSTRUMENT 6.

A maximum of about six analyses per hour can be made with this instrument when operated according to directions. By artificially cooling its indicating thermometer immediately following an analysis the number can be increased. With careful manipulation, analyses can be made with a maximum error of ± 0.3 per cent CO_2 .

The reagent is sodium hydroxide (NaOH) packed in small brass cartridges, one of which must be used for each analysis. The instrument is portable, compact, and convenient.

INSTRUMENT 7.

Seventeen to twenty analyses per hour can be made with instrument 7. With ordinary care an analysis can be made with a maximum error of ± 0.2 per cent CO_2 .

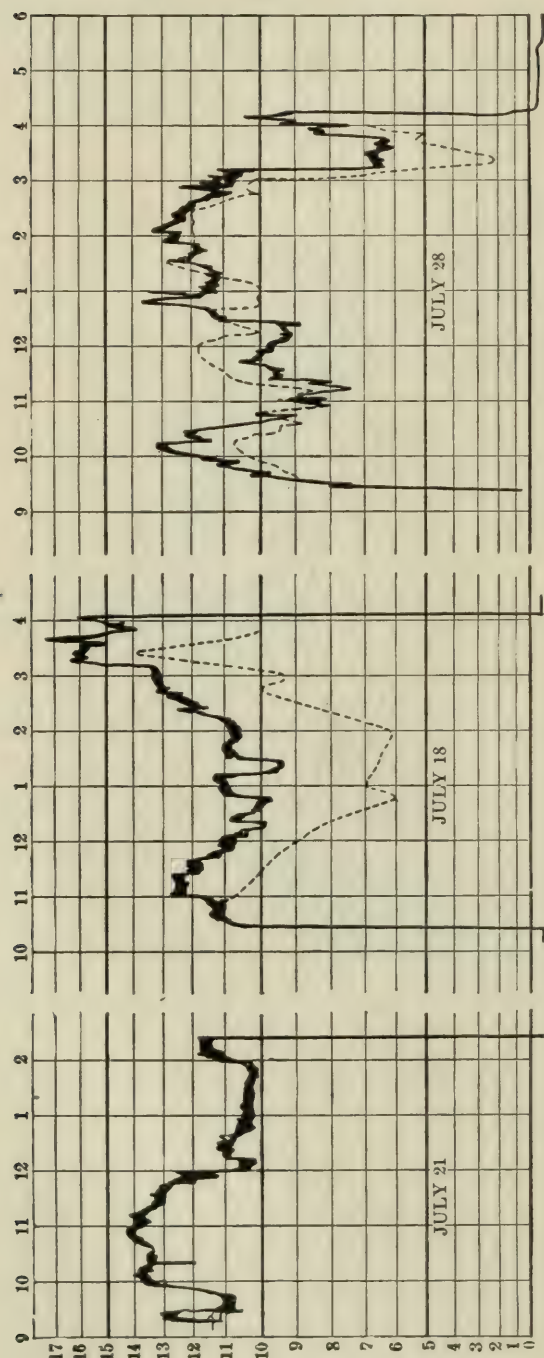


FIGURE 24.—Graphic record from instrument 4, normal operation. Dotted line shows true CO_2 content.

The reagent is a solution of potassium hydroxide in water. Several hundred analyses can be made with one charge of the caustic. The trouble most likely to be experienced is the sticking of the glass cock, owing to the action of the caustic. The device is compact and portable.

HINTS AS TO INSTALLING GAS LINE FOR ANY INSTRUMENT.

For the sampling pipe and gas line of any CO₂ recorder it is well to use three-fourths-inch pipe. A satisfactory way of arranging the pipe is to plug the end inserted into the boiler pass and drill small holes (one-eighth to three-sixteenths inch in diameter) every few inches in a line on one side of the pipe. The pipe is placed clear across the pass, at a convenient point in the gas travel, the small holes in the pipe being at

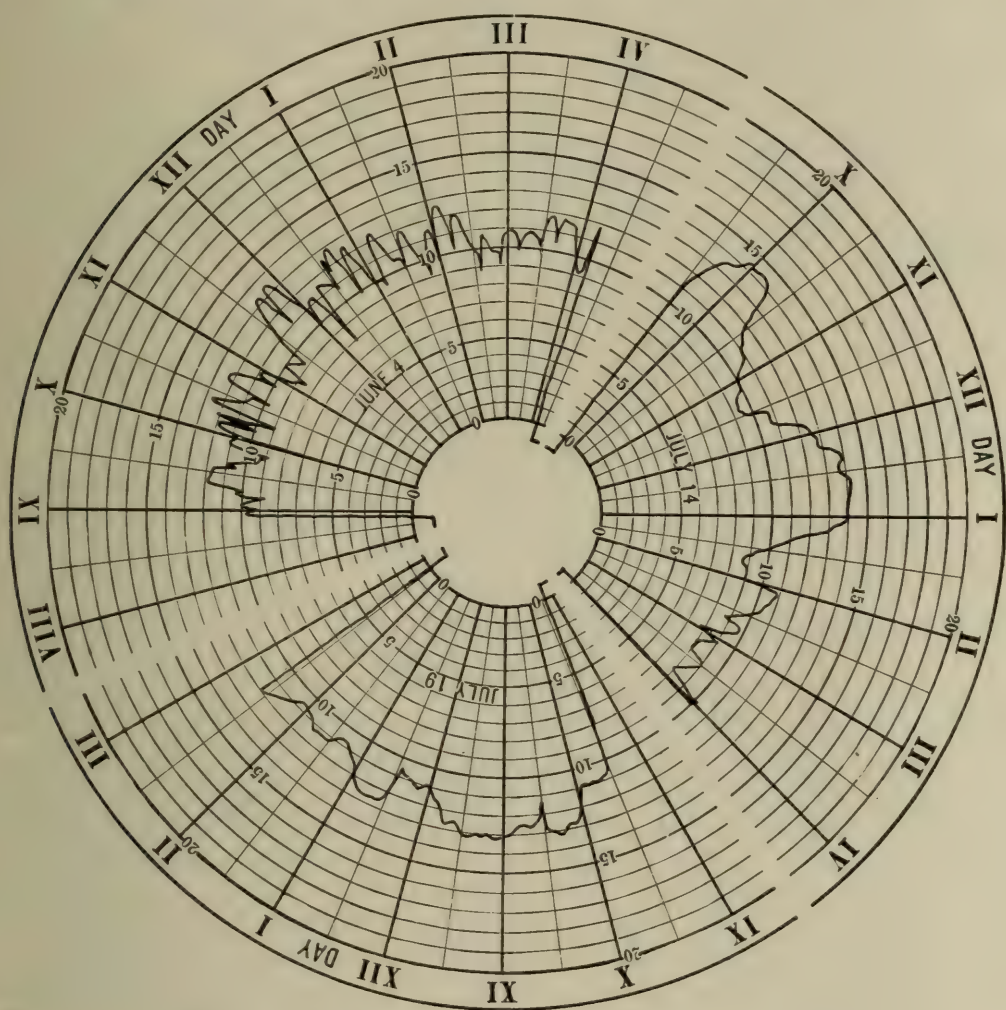


FIGURE 25.—Graphic record from instrument 5, normal operation.

right angles to the flow. The sampling pipe must be used at a place where the flue gases have become well mixed. Generally this can be found near the damper on the boiler side. Sluggish pockets of gas should be avoided.

All turns in the gas line should be made with crosses instead of elbows, the extra openings of the crosses being plugged. This plan allows the line to be easily cleaned. In running a gas line from the boiler to the filter and from the filter to the instrument proper, great care must be taken to insure a tight line so that the gas can not become mixed with outside air. Asphaltum paint should be used in the

joints and should be applied to the entire line after it has been connected. There should be a slight fall in the line toward the recorder, and sagging pockets should be avoided. Just in front of the instrument a vertical drop pipe should tap the pipe line. A small drain cock should be placed at the end of the drop pipe. Water can then accumulate in the drop pipe and be let out from time to time. The entire line should be so arranged that it can be blown out, preferably by compressed air or by steam. Each of the recorders has a manometer arrangement to show when the line becomes clogged to such an extent that blowing out is necessary.

Although the maker's instructions recommend that for each instrument the filter be as near as possible to the sampling tube, it may, under some conditions, be advisable to place the filter at a point in the sampling line near to the recorder in order to facilitate proper care of the filter.

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